CHARLES UNIVERSITY IN PRAGUE

Faculty of Physical Education and Sport UK

Department of Physiotherapy

Investigation of Insufficient Lumbopelvic Stability in Low Back Pain

Thesis submitted in fulfillment of the requirements for the degree of
MASTER IN PHYSIOTHERAPY

Supervisor:

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Abstract

Title: EN. Investigation of insufficient Lumbopelvic Stability in Low Back Pain.
CZ. Nedostatečná stabilita v oblasti bederní páteře a pánve u bolestí dolní části zad.

Thesis Aim: The aim is to present a group of concepts considering the stabilization system of the spine including the normal function and dysfunction of lumbopelvic-hip region approaching to LBP.

Methods: I performed a literature research review on articles related to this topic.

Results: Throughout our daily lives, humans transfer over 60% of bodyweight from the spine, across the pelvic articulations and hips to the lower limbs, during all weight bearing activities. In order to transfer these loads efficiently, motion and stability of the lumbar and pelvic articulations must be maintained at all times. Optimal stabilisation of the lumbo- pelvic region requires the integrated function of three systems: Passive osteo-ligamentous system (form closure), Active myo-fascial system (force closure) and Neural system (motor control).

Conclusion: Treatment of lumbo-pelvic dysfunction requires a multifaceted approach including: Biomechanical assessment of joint motion at the lumbar spine, pelvis, and hips. Assessment of patient's ability to control segmental motion, and load transfer through the lumbar spine & pelvis, plus postural assessment during functional activities and sports / employment specific tasks. Assess for neural deficits, neural mobility, and disc pathology. Treatment of biomechanical joint dysfunctions- lumbar spine, pelvis, and hips. Specific retraining of muscle activation and motor control in the lumbo-pelvic region, and flexibility of the lower limbs and trunk.

Key words: Low back pain, dysfunction, spinal stabilization, lumar, hip, sacrum, pelvic, biomechanics.

Declaration

I declare that this Master Thesis is based entirely on my own individual work, and on my own litterateur research. By the help of different books and journal databases on the internet, listed in the literature list in the end of this thesis, I managed to find all information needed for development of this Master thesis.

Abdulhamid Elrakayek

Prague, September 2012 ……………………………

Acknowledgement

The work presented in this thesis would not have been possible without my close association with many people who were always there when I needed them the most. I take this opportunity to acknowledge them and extend my sincere gratitude for helping me make this Master thesis a possibility.

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Abdulhamid Elrakayek

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Certificate of Completion of Thesis

This is to certify that the thesis entitled **"Investigation of Insufficient Lumbopelvic Stability in Low Back Pain**" is an authentic record of Master research carried out by **Abdulhamid Elrakayek**.

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Chapter I

1. Introduction

Low back pain is characterized by a range of symptoms which include pain, muscle tension or stiffness, and is localized between the shoulder blades and the folds of the buttocks, with or without spreading to the legs.

There are different definitions of low back pain depending on the choice of the source. According to the European Guidelines for prevention of low back pain, low back pain is defined as “pain and discomfort, localized below de costal margin and above the inferior gluteal folds, with or without leg pain” Another definition, according to S.Kinkade - resembles a lot on the one above of the European guidelines – is that low back pain is “pain that occurs posteriorly in the region between the lower rib margin and the proximal thighs”.

Low back pain is usually categorized in 3 subtypes: acute, sub-acute and chronic low back pain. This subdivision is based on the duration of the back pain. Acute low back pain is an episode of low back pain for less than 6 weeks, sub-acute low back pain between 6 and 12 weeks and chronic low back pain for 12 weeks or more.

Expert opinion has likened the frequency of LBP experienced by modern society to an “epidemic,” and reports in the literature consistently support this view. A recent systematic review estimated the 1-year incidence of a first-ever episode of LBP to range between 6.3% and 15.3%, while estimates of the 1-year incidence of any episode of low back pain range between 1.5% and 36% (Hoy D et al 2010). Low back pain is the leading cause of activity, limitation and work absence throughout much of the world and is associated with an enormous economic burden (Kent PM 2005, Thelin A et al 2008, Steenstra IA et al 2005). Also, individuals who have experienced activity-limiting LBP often experience reoccurring episodes with estimates ranging between 24% and 33% (Stanton TR et al 2008, Wasiak R et al 2003). Chronic low back pain has specifically demonstrated rapid increases.

While it is clear that individuals in all strata of society commonly experience LBP, its prevalence does appear to vary based on factors such as sex, age, education, and occupation. Women tend to have a higher prevalence of LPB than men, although the differences reported vary in magnitude (Bener A et al 2003, Oicavet HS et al 2003, Picavet HS et al 1999, Santos-Eggimann B et al 2000). An increase in age is also associated with higher prevalence of low back pain. The more severe forms of low back pain continue to increase with age (Dionne CE et al 2006) and the overall prevalence increases until ages 60 to 65 (Lawrence RC et al 1998, Loney PL et al 1999). Lower educational status is associated with increased prevalence of low back pain (Dionne CE et al 2006, Dionne CE et al 2001, Hoy D et al 2010, Reisbord LS 1985) as well as a longer episode duration and worse outcome (Dionne CE et al 2006).

Occupational differences in low back pain prevalence have also been reported (Hoy D et al 2010) with an association between higher physical demand and LBP prevalence (Matsui H et al 1997). Material workers were reported to have a LBP prevalence of 39%, whereas workers whose job responsibilities were classified as sedentary were reported to have a prevalence of 18.3% (Matsui H et al 1997).

Although differences exist between different occupational groups, similar LBP prevalence rates have been reported between working and nonworking groups (Picavet HS et al 1999).

Studies of risk factors are important because they seek to provide information about variables important in the etiology of mechanical LBP as well as the potential for resistance to recovery from LBP. A number of factors have been examined for their value in predicting the first onset of LBP. The 2 major categories of suspected risk factors for low back pain are individual and activity-related (work and leisure) factors. Individual factors include but are not limited to demographic, anthropometric, physical, and psychosocial factors.

The individual factors for which there is the most research include genetics, gender, age, body build, strength, and flexibility. Genetic factors have been linked to specific disorders of the spine such as disc degeneration (Battie MC et al 2006). The link of heredity to development of nonspecific LBP, however, remains questionable. A study by Battie demonstrated that there appears to be some relation between genetics, body build, and early environmental influences in determining the degenerative changes of the spine frequently associated with aging. Degenerative changes on magnetic resonance imaging (MRI), myelography, and computer-assisted tomography (CAT), however, are not strongly related to low back pain symptoms (Boden SD et al 1990, Hiselberger WE 1968, Wiesel SW et al 1984). There is some evidence that supports back pain associated with operating heavy equipment (Waters T et al 2008). Cardiovascular hypertension and lifestyle (smoking, overweight, obesity) risk factors are associated with sciatica. There is inconclusive evidence for a relationship between trunk muscle strength or mobility of the lumbar spine and the risk of low back pain (Hamberg-van Reenen HH et al 2007).

Psychosocial factors appear to play a larger prognostic role than physical factors in low back pain. There are some reviews that question if changes in behavioral variables and reductions of disability that facilitate an improvement in function may be more important than physical performance factors for successful treatment of chronic LBP (Wessels T 2006).

There is some evidence to suggest that fear may play a role when pain has become persistent (George SZ et al 2008, George SZ et al 2006). There is a growing consensus that distress/ depression plays an important role at early stages, and clinicians should focus on these factors (Pincus T et al 2002). Physical distress, depression, and fear avoidance are well-defined psychosocial entities that are best assessed with specific screening tools. There is no high-quality evidence to support pain-drawing use as a psychological assessment tool; therefore, pain drawings are not recommended for this purpose (Carnes D et al 2006).

Though some individual and lifestyle variables have been associated with prevalence of low back pain, the same factors may not have an influence on the recovery of patients who already have back pain. For example, a previous history of low back pain, job satisfaction, educational level, marital status, and number of dependents, smoking, working more than 8-hour shifts, occupation, and size of industry or company does not influence duration of sick leave due to low back pain (Steenstra IA et al 2005). In addition, the clinical course for patients with comorbidities, who may seem more complicated at the start of treatment, is just as favorable as for those without such co-morbidities (McIntosh G et al 2006). Consistent evidence was found for one's own expectations of recovery as a predictor for the decision to return to work. Patients with higher expectations had less sickness absence at the moment of follow-up measurement (Kuijer W et al 2006). Consistent evidence was found for the predictive value of pain intensity (more pain associated with worse outcome), several work-related parameters (eg, high satisfaction associated with better outcome), and coping style (active coping associated with better outcome) (van der Hulst M et al 2005).

In adolescents, the overall risk of low back pain is similar to adults, with prevalence rates as high as 70% to 80% by 20 years of age (Jones GT et 2005). Similar to adults, girls appear to have a higher prevalence, with 1 study demonstrating that females have almost 3 times the risk of back pain as their male counterparts (Viry P et al 1999).

Anthropometrics (eg, height, weight, body mass index) do not appear to be strongly associated with low back pain in adolescents, nor does lumbar mobility (Kujala UM et al 1997) or trunk muscle weakness (Balague F et al 1993). In adolescents, lifestyle factors that have been studied with respect to risk for low back pain include physical activity, sedentary activity, and mechanical load. With regard to physical activity, there appear to be mixed findings, with certain activities related to specific sports (eg, weightlifting, body building, rowing) associated with low back pain (Duggleby T et al 1997, Harvey J et al 1991, McKeeken J et al 2001). In cross-sectional studies, activity and prevalence of back pain take on a U-shaped function, with back pain increased at the sedentary and higher-activity ends (Taimela S et al 1976, Watson KD et al 2009).

However, in longitudinal studies, the relationship between modifying physical activity and back pain prevalence has not been well established (Jones M et al 2007, Salminen JJ 1995). As is the case in adults, psychological and psychosocial factors are commonly increased in children with low back pain and there is some evidence that such factors can predict future onset of LBP (Jones GT et al 2003, Jones MA et al 2004, and Watson DK et al 2003).

1.1 Lumbar spine - pelvic syndromes and LBP

Experimental studies suggest that low back pain may originate from many spinal structures, including ligaments, facet joints, the vertebral periosteum, the paravertebral musculature and fascia, blood vessels, the anulus fibrosus, and spinal nerve roots. Perhaps most common are musculoligamentous injuries and age-related degenerative processes in the intervertebral disks and facet joints. Other common problems include spinal stenosis and disk herniation. Stenosis is narrowing of the central spinal canal or its lateral recesses, typically from hypertrophic degenerative changes in spinal structures. The most common form of low back pain is the one that is called "non-specific low back pain" and is defined as "low back pain not attributed to recognizable, known specific pathology".

The principal syndromes of the lumbar spine and pelvis that give rise to low back and leg pains are described as below. Within each syndrome there are several subsyndromes (Paris 2002).

1.2.1 Myofascial states

Changes in the myofascia will invariably accompany back pain, regardless of its origin. Not all myofascial changes, particularly those relating to changes in tone, require treatment, but they always require consideration. 'Tone' is defined as the normal elasticity of a muscle to stretch or touch. When we palpate a muscle and speak of its 'tone', we are actually speaking of its response to our touch as it elastically (linear response) contracts against our deforming palpation in order to protect its muscle spindles from further deformation.

Hypertonic states

Spasm: There is no doubt that 'spasm' is one of the most misused terms in orthopedics because it is frequently used to describe any noted change in muscles. True spasm is defined as a 'sudden involuntary contraction of one or more muscle groups'. Thus patients who are rigidly splinting their back in flexion or any other posture are not demonstrating 'spasm' but rather what this author recognizes as 'muscle splinting.'

There are several types of muscle splinting, some of which can benefit from treatment whereas others can be ignored while attention is directed at the cause. Thus the term 'spasm' should be reserved for sudden involuntary twitches of muscle denoting such possibilities as pain, instability, or apprehension.

Hypertrophy: Hypertrophy commonly results from muscle training as in body building. Such muscles are at an increased tone even at rest and might unduly load the spine, impede nutrition at rest, and enable extreme weight to be lifted contributing to such fatigue fractures as spondylolisthesis.

Involuntary splinting

This is the most common of the hypertonic muscle states, usually involving the multifidus group, and will invariably coexist with most underlying dysfunctions. No doubt the muscle response is produced by nociception in an effort to splint the back from further stress and injury. It will be relieved immediately by lying down with adequate support. Unfortunately, muscle splinting increases the load on the spinal segments and should the nociception actually arise from the disc this would invariably aggravate the situation.

Chemical splinting: Should involuntary splinting continue it will result in the retention of waste products, which will give rise to back pain. Much of low back pain is due to persistent muscle splinting secondary to the underlying disc, facet, or sacroiliac problem. Another cause of chemical muscle splinting is from simple overuse, as can be experienced in, say, the quadriceps after an unaccustomed run or climb. The muscles retaining waste metabolites will appear to have an elevated resting tone and are tender and doughy to touch. Massage is of great help to relieve this discomfort and promote motion, and some patients learn that by 'cracking' their back they can relieve this discomfort.

Voluntary splinting: Should nociception reach the threshold for pain, the patient might voluntarily splint the affected parts, holding them against segmental motion much as a person with a painful shoulder might hold the arm to the side.

Psychosomatic stress: The possibility that psychosomatic stress might result in altered low back function must not be ignored. Tension can give rise to headaches, clenching jaw, and temporomandibular joint dysfunction, and low back pain.

Hypotonic states

Disuse atrophy: Disuse atrophy will occur in any back which for either pain or stiffness has resulted in a loss of normal mobility. The muscle will appear to have lost bulk, lack normal tone and be somewhat fibrous to palpation.

Wasting and fibrosis: Like disuse atrophy, this condition is more likely the result of neurological or surgical interference with normal nerve conduction. The muscles waste and appear fibrositic.

Physiological tone/shortened

Adaptive shortening:Adaptive shortening, which is initially a loss of sarcomeres and later a shortening of the intra muscular connective tissues, results from muscle being held in a shortened position. A typical example is the overweight male with a pendulous abdomen. This posture results in an increased lumbar lordosis leading to posterior muscle shortening and limited hip extension secondary to shortening of psoas and associated muscles. This example of adaptive shortening can contribute to spinal stenosis.

Compartmental syndrome: When muscles in the lumbar spine hypertrophy, owing either to muscle splinting, instability, a change in the work environment, or body-building activities, they can become restricted in their fascial compartments, resulting in a chronic uni- or bilateral paravertebral back pain. The muscles will feel tender to the touch.

Fibrositis: The 'nodules' that can be palpated in muscle are not presented until palpated for. This apparent contradiction is explained by the fact that the palpating finger stretches the muscle spindle causing the fiber in which it resides to contract thus giving rise to a 'nodule' like feeling. These nodules are therefore a physiological response to touch. However, around the iliac crest, just lateral to multifidus insertion, there are a number of fatty nodules that seem to be without pathology but like all structures will be tender when the back is experiencing sufficient dysfunction.

1.2.2 Facet dysfunction

The spinal facet joints, particularly their posterior medial aspect, are perhaps the most innervated structures in the spine (Paris SV 1984). Since the 1930s, they have been identified as a source of pain and have been the subject of a number of studies involving the reproduction of pain by injecting hypertonic saline (Mooney & Robinson 1976). We can identify five separate clinical states in the spinal facets, which should not come as a surprise, as all five can exist in other synovial joints, such as the knee, which, in common with the spinal facets, have meniscal inclusions. These states are described below.

Facet synovitisfhemarthrosis (acute sprain): Acute synovitis or hemarthrosis is perhaps the most common source of acute, usually transient, low back pain. Its cause appears to be a strain or nipping of the sensitive facet capsule and its synovial lining following an awkward or forceful movement. Depending on the degree of noxious stimulation, it is accompanied by involuntary or voluntary muscle guarding. It is widely accepted that 80% of back pain resolves within 2 weeks and in the view of these authors most of these cases are facet injuries.

Typically, the injury occurs when the spine is moved in a sudden motion or in recovering with a twist from a forward bent position. Although three structures are designed to prevent capsular fupping [the elastic anterior capsule (ligamentum flavum), the intracapsular fibrous meniscoid, and the attachment of the multifidus muscle posteriorly], these mechanisms can fail and a painful nipping can result. The joint swells and the nipping is relieved. The initial pain is sharp and often quite localized and, in the cervical spine, can be readily palpated.

The signs and symptoms are of localized low back pain and minimal radiation, perhaps to the iliac crest and buttock (further if there is a memory of sciatic pain from past problems). The effusion would be expected to resolve in 2-3 days as with other joints, will leave behind some restrictions to movement.

This will be the case especially if the injury resulted in hemarthrosis and thus the deposition of fibrinogen into the joint leading to the formation of intra-articular adhesions (Paris SV 2002).

These restrictions help to splint the sensitive joint, thus enabling the muscle splinting to abate and the patient to move more freely. Such restrictions leave the joint less able to tolerate future insults, making it even more prone to reinjury, and resulting again in synovitis and hemarthrosis. Restrictions of facets also serve to limit nutrition to the intervertebral disc.

Facet stiffness (restrictions): Spinal facet restriction is very common and is a painless condition, as is initial stiffness in joints of the extremities. However, stiffness leads to loss of nutrition and hence aids degeneration. Especially in the spine - where stiff facets combined with adaptive muscle shortening can lead to interference with disc nutrition and precipitate disc degeneration, herniation, and prolapse. As stiff joints do not necessarily hurt, they are usually detected on examination for back pain from other causes. Segmental restrictions are detected with passive motion testing (motion palpation, Gonella et al 1982).

Facet painful entrapment: The patient reports with acute low back pain and postural deviation away from the painful side. The postural change came on immediately following the injury. Any effort to resume normal alignment is accompanied by a local and sharp pain on one side of the back. The pain does not radiate, but might - a day or so later - migrate up the spine owing to painful involuntary muscle guarding, leading to chemical muscle holding.

Facet mechanical block: In contrast to painful block, a mechanical block is relatively painless but again is immediate following an awkward motion. The patient quite simply becomes suddenly fixed in a laterally shifted position. Any attempt to straighten upward is met with difficulty, and the patient often reports being 'stuck' and in need of having it 'cracked.' The exact mechanism is speculative.

However, as spinal facets contain menisci, and on occasion loose bodies, and such joints elsewhere in the body (the knee, craniomandibular joint, and wrist) are known to become stuck or locked, it is surely possible that the spinal facets might also lock.

Chronic facet dysfunction: This condition results from repeated strains and sprains to the facet joints and is no different from degenerative arthrosis affecting synovial joints elsewhere in the body. Stiffness and pain is felt on rising, with stiffness easing and pain increasing towards the end of the day. A facet block can be diagnostic if both the traditional joint as well as its medial compartment is injected.

1.2.3 Ligamentous weakness and instability

The term 'instability' has received considerable attention since the 1990s. Instability will occur when the osseo ligamentous and neuromuscular components of the segment are unable to hold the spine against slippage in neutral during sitting and standing and during movement against aberrant motions.

Ligamentous laxity can be a source of pain in peripheral joints such as the knee, glenohumeral, and acromioclavicular joints. It is now accepted that the same situation is commonly present in the spine (Kirkaldy-Willis 1990, Nachemson 1985). The structures responsible for passive spinal stability are initially the ligamentous structures, including the outer annulus of the intervertebral disc, which is likewise made up of type I stress-resistant collagen.

The facet joints also play a variable role in passive spinal stabilization and their surgical removal will help to create instability. Additionally, the posterior muscles of the spine are important in achieving stabilization, especially the muscle multifidus. In some quarters, a great deal of attention has been given to the stabilizing role of the transverse abdominus, which no doubt is important but as a result it would seem that too little attention has been given to the remaining abdominal muscles especially the obliques.

Ligamentous weakness precedes segmental ligamentous instability, and instability is a precursor of the clinically apparent disc condition perhaps requiring surgery with or without fusion. A stable spine appears far less likely to present with a clinically obvious disc problem.

The pain of ligamentous weakness is begins with a dull ache in the back, which, as the day wears on, appears to spread to the muscles (the muscles are actually in chemical muscle holding). This ache can be relieved by a change in position, movement, and massage or by 'self-cracking' of the back. The 'self-cracking' is not to be recommended as it severely stresses the disc, leading to further instability, and although it might provide temporary relief, it does so at the expense of stability.

Given that ligamentous weakness also involves the annulus fibrosus, transient neurological signs might occur, as might a transient lateral shift, again toward the end of the day. Such a lateral shift can be considered to be a sign of instability. Causes of spinal instability are, no doubt, to be found in postural misuse and abuse, smoking and poor nutrition. The clinical signs and symptoms of instability (Paris SV 1985) include:

- A visible or palpable step or rotary deformity, which is present on standing but which reduces on lying.
- Hypertonicity of the muscles on standing that disappears on lying.
- Hypermobility on motion passive palpation: grade 5 or 6 (Gonnella et al 1982).
- Shaking or trembling of the lumbar spine on forward bending.
- More difficulty in coming upright than going into forward bending.

1.2.4 Sacroiliac dysfunction

The principal source of pain arising from the sacroiliac (SI) is, the richly innervated, strong, deep posterior SI ligaments (Paris 1983), which are designed to resist principally vertical stresses and some element of rotation in the female. The iliolumbar ligament is also a key SI ligament and, when strained, will also give rise to lateral low back pain, which can be confused with sacroiliac pain.

Acute strain: Acute strain is most commonly caused by a fall on one of the ischial tuberosities. If the ligaments are strong, they will resist a displacement but it might be quite painful for a few days. The pain is local as is the tenderness.

Hypermobility: Hypermobility is caused by repeated sprains and strains, such as in falls, poor postural habits, as in one-leg standing, and vigorous positions in sexual intercourse wherein the thighs are repeatedly forced toward the chest - this is especially the case in those with restricted hip motion. All of the above activities cause the ilium to rotate posteriorly. Once the joint is hypermobile it will ache on prolonged standing, especially one-legged standing and will be eased almost immediately by lying supine. Standing rotates the ilium posteriorly in the female whereas lying rotates it anteriorly. The pain is also increased, as with all l igamentous and discogenic pains, in the days just prior to the menstrual flow.

Displacement (subluxation): The hypermobile sacroiliac is most likely to result in a displacement and a resultant 'lock' of the irregular articular surfaces. The pain that was intermittent during the preceding period of hypermobility is now of a lower degree but is constant - even in lying.

1.2.5 Disc dysfunction

In virtually all patients with a clinically evident disc protrusion or rupture (presence of paresis) there is first a preceding history of ligamentous weakness and/ or spinal instability. This raises the possibility that disc prolapses are the result of failure to intervene with conservative care, i.e. manual physical therapy.

For a clinical disc protrusion and/ or prolapse to be diagnosed, there must be demonstrable neurological signs other than pain below the knee and limited straight leg raising. Straight leg raise can be limited by hip, sacroiliac, and muscular tenderness. Objective muscle weakness (paresis) and loss of skin sensation are indicative of nerve root involvement. Reduced or absent reflexes are less indicative. An analysis shows that even in the presence of paresis, conservative care is equal to or better than disc surgery and that aggressive conservative care is better than either (Saal & Saal 1989). The nonoperative treatment will depend on the stage of the condition.

Immediate stage: This stage occurs when the patient, who has a history of ligamentous weakness and/ or instability, performs an awkward or unguarded action and feels something' give' or ' tear' in his or her back. In such circumstances, especially if there is a history of low back pain and instability, it is a real possibility that the disc has just torn.

The patient should immediately stand erect and maintain a lordosis to close down the tear and help promote healing. However, most people who injure their back are wont to sit down and rest. Unfortunately, sitting increases the load on the disc and might well place the patient in a kyphosis, which opens the tear and allows the nucleus to imbibe fluids and expand out through the tear. The lordotic posture should be maintained with the assistance of taping for 2 weeks, after which the back can rest flat; flexion should be avoided for at least 6 weeks.

Acute stage: Here we presume that the disc is protruded/ extruded and the nerve root is compromised and that the opportunity to contain it by having gone immediately into backward bending (lordosis) is lost. Any attempt to go into backward bending at this stage may increase the size of the protrusion bringing it more firmly onto the nerve thus increasing symptoms (McCall 1980, Spohr & Paris SV 1992).

Subacute: The symptoms will begin to recede some 3 to 5 days after injury. The patient should be encouraged to ambulate and get moving. A walker or crutches can help. Periods of moving should be alternated with rest on a firm surface with the back flat to assist in disc nutrition and to avoid strain on the disc. The outer annulus appears to be more vascular than the medial ligament at the knee and so healing of the tear can be expected (Paris SV 1990). Sitting is to be discouraged, especially in a soft sofa or automobile seat.

Chronic stage: This is at about 12 weeks, when all primary healing has taken place, and in a patient who still has symptoms.

1.2.6 Spondylolisthesis

There are several types of spondylolisthesis. The most common is from a fatigue fracture of the pars interarticularis. Whatever the cause, a palpable 'step' and/ or 'rotation' can be detected in the back when standing. If the step or rotation disappears with lying, the slip can be considered to be unstable. X-ray confirmation should be taken, with the patient standing to maximize displacement. Lying films might fail to show a degenerative spondylolisthesis if it is unstable and has self-reduced with lying.

The symptoms are ligamentous and local. Up to a grade I displacement (one-fifth slip) might not be the source of the patient's symptoms, as many such subjects can be found to be without back pain. Only if the slip is advanced will neurological signs and symptoms result.

1.2.7 Central canal and lateral foraminal stenosis

The typical patient is middle-aged to elderly, short, and heavy framed, with a history of a lifestyle that is physically stressful to the lumbar spine; the patient is perhaps obese, diabetic, and has a history of smoking.

The signs and symptoms are extremely variable but include transient neurological signs and symptoms brought on by exercising, particularly in the afternoon. Neurovascular claudication occurs during walking, similar to vascular claudication, but is distinguished by the fact that forward bending tends to relieve the pain. The bicycle test is confirmatory. Riding a stationary bicycle with the back in lordosis will soon bring on leg pain, but riding the bicycle with the low back in kyphosis will delay or even prevent the onset of pain.

1.2.8 Baastrup's sign

Baastrup described a condition in which the spinous processes of the lumbar spine impinge on one another and give rise to arthritis and sclerotic changes, which can become quite painful. The condition is most common in short, stocky males at middle life. It is in these individuals that the spinous processes tend to be large and the disc spaces small.

With middle age and the natural shrinking of the intervertebral disc, the spinous processes impinge on one another, producing central low back pain relieved by forward bending or pulling the knees to the chest (Baastrup 1933).

1.2.9 Thoracolumbar syndrome

Perhaps first described by Maigne, this instability condition at the thorocolumbar junction gives rise to irritation of the lateral cutaneous nerve to the thigh and a 'radicular' type of pain referral to the area of the hip joint and surrounding tissues. There is usually tenderness where the nerve crosses the posterior iliac crest. The condition appears to originate from the T11-L1 levels, sometimes secondary to stiffness or surgical fusion of the lower levels.

Since back pain can arise from one or a combination of the above listed sources, it is important for the practicing clinician to do a thorough examination in order to attempt to identify and treat the cause of the pain and its contributing factors, rather than treat the pain itself (Paris SV 1992).

1.2 Spinal stability concept

Low Back Pain is a well-recognized problem worldwide, spinal instability is considered to be one of the important causes of LBP but is poorly defined and not well understood. The basic concept of spinal instability is that abnormally large intervertebral motions cause either compression and/or stretching of the inflamed neural elements or abnormal deformations of ligaments, joint capsules, annular fibers, and end-plates, which are known to have significant density of nocioceptors. In both situations the abnormally large intervertebral motions may produce pain sensation. The purpose of this part is to present a group of concepts considering the stabilization system of the spine including the normal function and dysfunction.

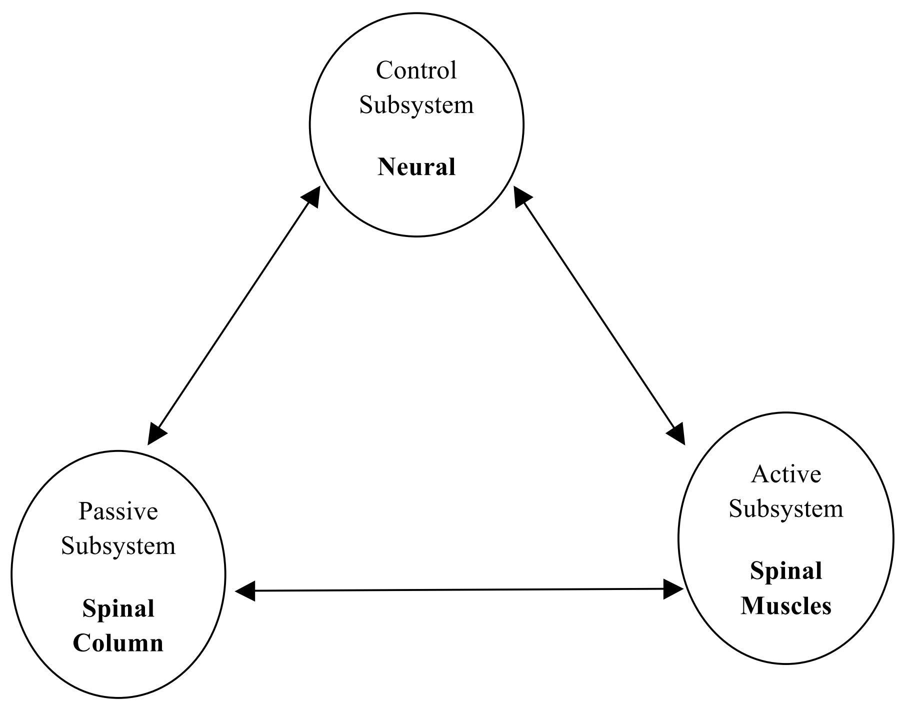

FIG. 1. *The spinal stability system consists of three subsystems: passive spinal column, active spinal muscles, and neural control unit.*

The spinal stabilizing system is conceptualized as consisting of three subsystems (Fig. 1). The *passive musculoskeletal subsystem* includes vertebrae, facet articulations, intervertebral discs, spinal ligaments, and joint capsules, as well as the passive mechanical properties of the muscles. The *active musculoskeletal subsystem* consists of the muscles and tendons surrounding the spinal column. The *neural and feedback subsystem* consists of the various force and motion transducers, located in ligaments, tendons, and muscles, and the neural control centers. These passive, active, and neural control subsystems, although conceptually separate, are functionally interdependent.

1.3 Normal function of the spinal stabilizing system

The normal function of the stabilizing system is to provide sufficient stability to the spine to match the instantaneously varying stability demands due to changes in spinal posture, and static and dynamic loads. The three subsystems work together to achieve the goal as described in subsequent paragraphs and schematically shown in (Fig. 2).

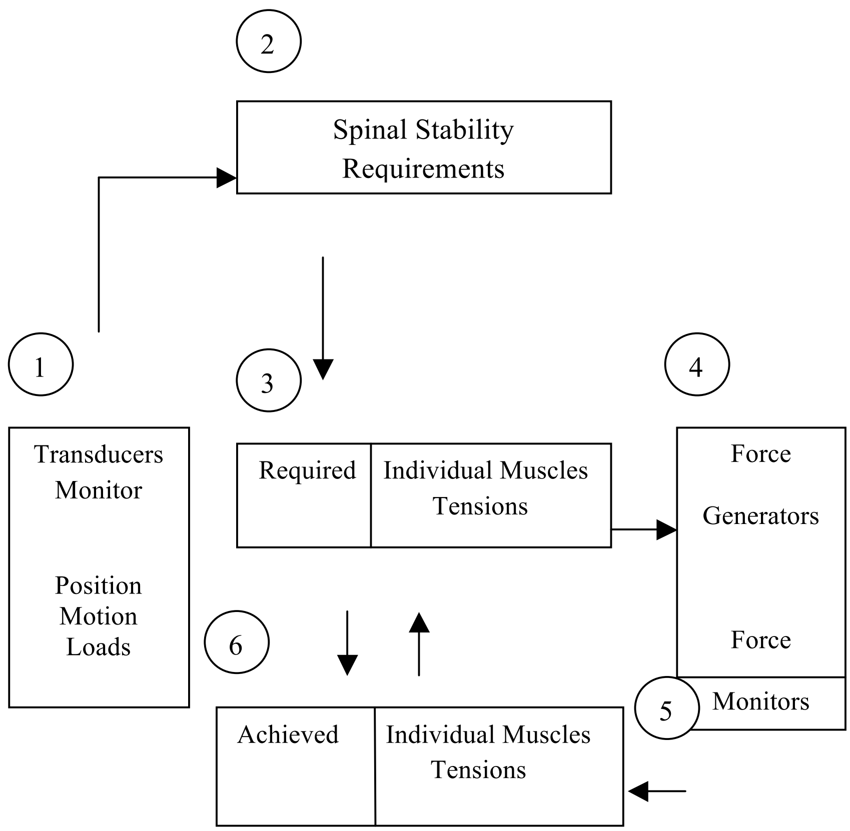

FIG. 2. *Functioning of the spinal stability system. The information from the (1) Passive Subsystem sets up specific (2) spinal stability requirements. Consequently, requirements for (3) individual muscle tensions are determined by the neural control unit. The message is sent to the (4) force generators. Feedback is provided by the (5) force monitors by comparing the (6) "achieved" and (3) "required" individual muscle tensions [Panjabi, 1992]*

1.3.1 The Passive (Ligamentous) Subsystem

Components of the passive subsystem, (e.g., ligaments) do not provide any significant stability to the spine in the vicinity of the neutral position. It is toward the ends of the ranges of motion that the ligaments develop reactive forces that resist spinal motion. The passive components probably function in the vicinity of the neutral position as transducers (signal- producing devices) for measuring vertebral positions and motions, similar to those proposed for the knee ligaments and therefore are part of the neural control subsystem. Thus, this subsystem is passive only in the sense that it by itself does not generate or produce spinal motions, but it is dynamically active in monitoring the transducer signals.

1.3.2 The Active (Musculotendenous) Subsystem

The muscles and tendons of the active subsystem are the means through which the spinal system generates forces and provides the required stability to the spine. The magnitude of the force generated in each muscle is measured by the force transducers built into the tendons of the muscles. Therefore, this aspect of the tendons is part of the neural control subsystem.

1.3.3 The Neural Control Subsystem

The neural subsystem receives information from the various transducers, determines specific requirements for spinal stability, and causes the active subsystem to achieve the stability goal. Individual muscle tension is measured and adjusted until the required stability is achieved. The requirements for the spinal stability and, therefore, the individual muscle tensions, are dependent on dynamic posture, that is, variation of lever arms and inertial loads of different masses, and external loads.

1.4 Dysfunction of the spinal stabilizing system

Degradation of the spinal system may be due to injury, degeneration, and/or disease of any one of the subsystems (Fig. 3). The neural control subsystem perceives these deficiencies, which may develop suddenly or gradually, and attempts to compensate by initiating appropriate changes in the active subsystem. Although the necessary stability of the spine overall may be reestablished, the subsequent consequences may be deleterious to the individual components of the spinal system (e.g., accelerated degeneration of the various components of the spinal column, muscle spasm, injury, and fatigue). Over time, the consequences may be chronic dysfunction and pain.

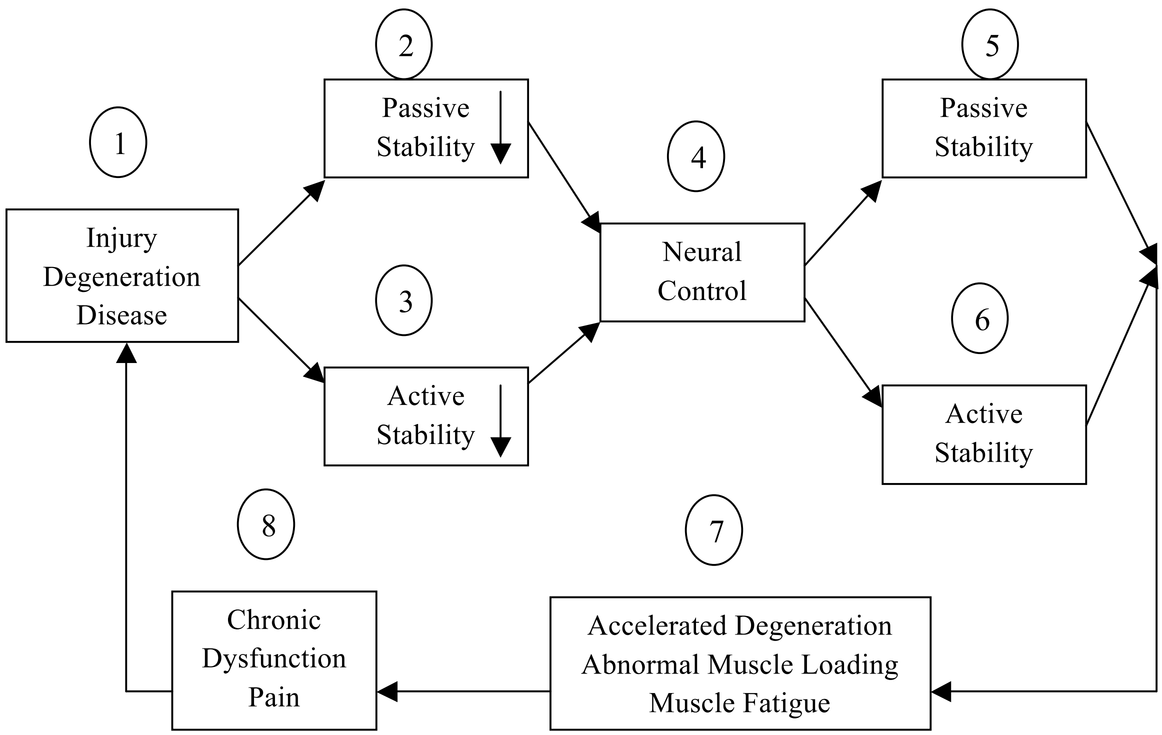

FIG.3. *Dysfunction of the spinal stability system. (1) Injury, degeneration and/or disease may decrease the (2) passive stability and/or (3) active stability. (4) The neural control unit attempts to remedy the stability loss by increasing the stabilizing function of the remaining spinal components: (5) passive and (6) active. This may lead to (7) accelerated degeneration, abnormal muscle loading, and muscle fatigue. If these changes cannot adequately compensate for the stability loss, a (8) chronic dysfunction or pain may develop [Panjabi, 1992]*

1.5 Principles functions of lumbopelvic–hip region

According to Lee & Vleeming 1998, 2003, the integrated model of function (Fig. 4) has four components.

- form closure (structure)
- force closure (forces produced by myofascial action)
- motor control (specific timing of muscle action/inaction during loading)
- psychological: emotions

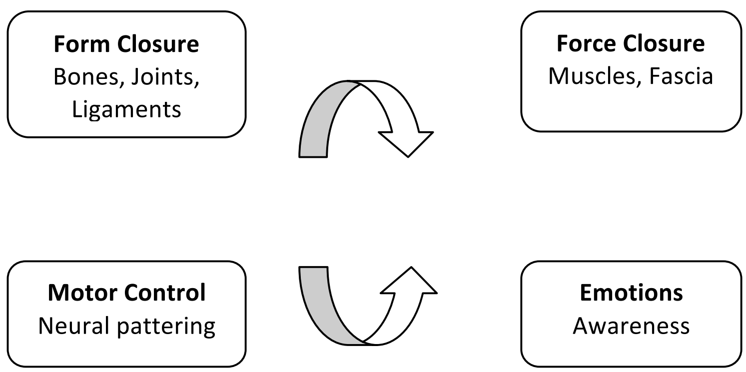

FIG. 4. *The integrated model of function [Lee ft Vleeming1998]*

A primary function of the lumbopelvic - hip region is to transfer the loads generated by body weight and gravity during standing, walking, and sitting (Snijders et al 1993a, b). According to (Panjabi 1992a, b) stability (effective load transfer) is achieved when the passive, active, and control systems work together (Fig. 1) believe that the passive, active, and control systems produce approximation of the joint surfaces, which is essential if stability is to be insured. The amount of approximation required is variable and difficult to quantify since it is essentially dependent on an individual's structure (form closure) and the forces they need to control (force closure).

The term "adequate" has been used by (Lee & Vleeming 1998, 2003) to describe how much approximation is necessary and reflects the non-quantitative aspect of this measure.

The ability of transfer load through the pelvis effectively is dynamic and depends on:

- Optimal function of the bones, joints, and ligaments (form closure) (Vleeming et al 1990a,b)
- Optimal function of the muscles and fascia (force closure) (Vleeming et al 1995b, Richardson et al 1999, 2002, O'Sullivan 2000, Hungerford 2002)
- Appropriate neural function (motor control, emotional state) (Bo & Stein 1994, Holstege et al 1996, Hodges 1997,2003a, Hodges et al 1999, 2001c, 2003b, Hodges & Gandevia 2000b, Hungerfird 2002)

1.5.1 Form closure

The term "form closure" was coined by Vleeming & Snijders and is used to describe how the joint's structure, orientation, and shape contribute to stability and potential mobility. All joints have a variable amount of form closure and the individual's inherent anatomy will dictate how much additional force (force closure) is needed to ensure stabilization when loads are increased.

1.5.1.1 Lumbar spine

Compression: Compression of an object results when two forces act towards each other. The main restraint to compression in the lumbar spine is the vertebral body / annulusnucleus unit, although the zygapophyseal joints have been noted (Farfan 1973, Kirkaldy-Willis 1983, Gracovetsky et al 1985, Gracovetsky & Farfan 1986, Bogduk 1997) to support up to 20% of the axial compression loads (Fig. 5). Both the annulus and the nucleus transmit the load equally to the end-plate of the vertebral body. The thin cortical shell of the vertebral body provides the bulk of the compression strength, being simultaneously supported by a hydraulic mechanism \within the cancellous core, the contribution of which is dependent upon the rate of loading. When compression is applied slowly (static loading), the nuclear pressure rises, distributing its force on to the annulus and the end-plates.

The annulus bulges circumferentially and the endplates bow towards the vertebral bodies. Fluid is squeezed out of the cancellous core via the veins; however, when the rate of compression is increased, the small vessel size may retard the rate of outflow such that the internal pressure of the vertebral body rises, thus increasing the compressive strength of the unit. In this manner, the vertebral body supports and protects the intervertebral disk against compression overload (McGill 2002). The anatomical structure which initially yields to high loads of compression is the hyaline cartilage of the end-plate, suggesting that this structure is weaker than the peripheral parts of the end-plate (Bogduk 1997).

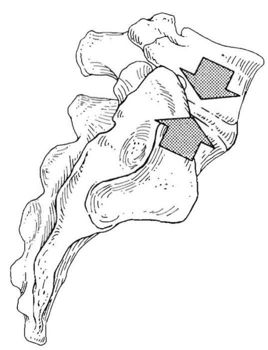

FIG. 5. *Compression of lumbosacral junction*

Torsion or rotation: When a force is applied to an object at any location other than the center of rotation, it will cause the object to rotate about an axis through this pivot point. The magnitude of the torque force can be calculated by multiplying the quantity of the force by the distance the force acts from the pivot. Axial rotation of the lumbar vertebra occurs when the bone rotates about a vertical axis through the center of the body (Fig. 6) and is resisted by anatomical factors located within the vertebral arch (65%) as well as by the structures of the vertebral body /intervertebral disk unit (35%) (Gracovetsky & Farfan 1986) (Bogduk 1997).

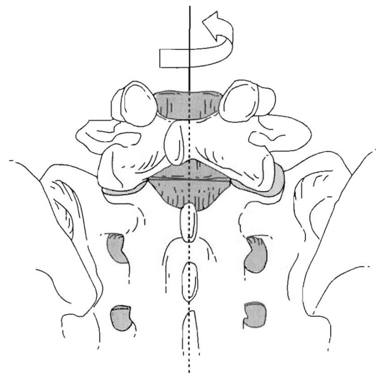

FIG. 6. *Right axial torsion of the L5 vertebra is resisted by osseous impaction of t he left zygapophyseal joint and capsular distraction of the right zygapophyseal joint as well as the segmental ligaments, the intervertebral disk, and the myofascia.*

At the lumbosacral junction, the superior articular process of the sacrum is squat and strong in comparison to the inferior articular process of the L5 vertebra which is much longer and receives less support from the pedicle. Consequently, the inferior process is more easily deflected when the zygapophyseal joint is loaded at 90° to its articular surface. This process can deflect 8-9° medially during axial torsion beyond which trabecular fractures and residual strain deformation will occur (Farfan 1973, Bogduk 1997).

The structure and orientation of the annular fibers are critical to the ability of the intervertebral disk to resist torsion. "The concentric arrangement of the collagenous layers of the annulus ensures that when the disk is placed in tension, shear or rotation, the individual fibers are always in tension" (Kirkaldy-Willis 1983). Under static loading conditions, injuries occur with as little as 2° and certainly by 3.5˚ of axial rotation (Gracovetsky & Farfan 1986). The iliolumbar ligament plays an important role in minimizing torque forces at the lumbosacral junction. The longer the transverse process of the L5 vertebra and consequently the shorter the iliolumbar ligament, the stronger is the resistance of the segment to torsion (Farfan 1973).

Axial compression also increases the segmental torque strength by 35% (Gracovetsky & Farfan 1986). During forward flexion of the lumbar spine, the instantaneous center of rotation moves forward, thus increasing the compressive load and consequently the ability of the joint to resist torsion.

Posteroanterior translation: Translation occurs when an applied force produces sliding between two planes. Posteroanterior translation occurs in the lumbar spine when a force attempts to displace a superior vertebra anterior to the one below (Fig. 7). The anatomical factors which resist posteroanterior shear at the lumbosacral junction are primarily the impaction of the inferior articular processes of L5 against the superior articular processes of the sacrum and the iliolumbar ligaments (Bogduk 1997). Secondary factors include the intervertebral disk, the anterior longitudinal ligament, the posterior longitudinal ligament, and the midline posterior ligamentous system.

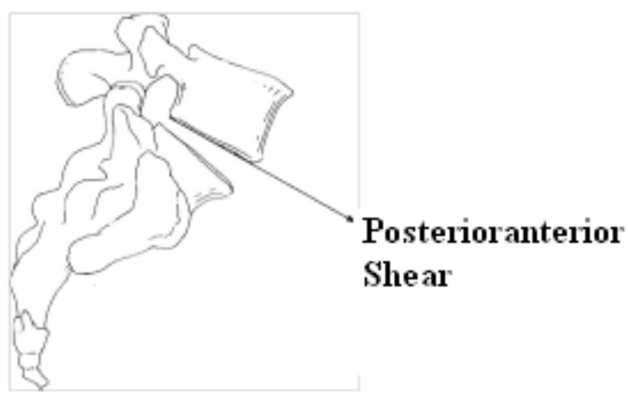

FIG. 7. *Posteroanterior shear of the L5 vertebra on the sacrum*

Dynamically, the posterior midline ligaments, the thoracodorsal fascia, and the muscles which generate tension within this system are important in balancing the anterior shear forces which occur when large loads are lifted (force closure) (Gracovetsky & Farfan 1986, Vleeming et al 1990a, b, 1995a, 1997, Hides et al 1994, 1996, Richardson & Jull 1995, Hodges & Richardson 1996, Adams & Dolan 1997, Bogduk 1997, Hodges et al 2003b). The optimal method of loading the spine should balance both compression and translation such that the magnitude of the resultant force does not exceed the strength of the joint.

Consequently, both the articular (form closure) and the myofascial components (force closure) are required to balance the moment of a large external load.

1.5.1.2 Pelvic girdle

The SIJs transfer large loads and their shape is adapted to this task. The articular surfaces are relatively flat and this helps to transfer compression forces and bending moments (Vleeming et al 1990a, b, Snijders et al 1993a, b). However, a relatively flat joint is theoretically more vulnerable to shear forces. The SIJ is anatomically protected from shear in three ways.

First, the sacnun is wedgeshaped in both the anteroposterior and vertical planes and thus is stabilized by the innominates. The articular surface of the SIJ is comprised of two to three sacral segments and each is oriented differently (Solonen 1957).

Second, in contrast to other synovial joints, the articular cartilage is not smooth but irregular, especially on the ilium (Sashin 1930, Bowen & Cassidy 1981).

Third, a frontal dissection through the SIJ reveals cartilage-covered bony extensions protruding into the joint (Vleeming et al 1990a), ridges, and grooves. They seem irregular, but are in fact complementary. All three factors enhance stabilization of the SIJ when compression (force closure) is applied to the pelvis. Again, both the articular (form closure) and the myofascial components (force closure) are required to balance the moment of a large external load.

The pubic symphysis has less form closure than the SIJ in that the joint surfaces are relatively flat. The joint surfaces are bound by a fibrocartilatinous disk which is supported externally by superior, inferior, anterior, and posterior ligaments. T he pubic symphysis is vulnerable to shear forces in both the vertical and horizontal plane and relies on dynamic elements (myofascia), in addition to the passive structures, for stability.

1.5.1.3 Hip joint

The hip is subjected to forces equal to multiples of the body weight and requires osseous, articular, and myofascial integrity for stability. The form closure factors which contribute to stability at the hip include the anatomical configuration of the joint as well as the orientation of the trabeculae and the orientation of the capsule and the ligaments during habitual movements.

During erect standing, the superincumbent body weight is distributed equally through the pelvic girdle to the femoral heads and necks. Each hip joint supports approximately 33% of the body weight which subsequently produces a bending moment between the neck of the femur and its shaft (Singleton & LeVeau 1975). A complex system of bony trabeculae exists within the femoral head and neck to prevent superoinferior shearing of the femoral head during erect standing. The hip joint is an unmodified ovoid joint, a deep ball and socket, and its shape precludes significant shearing in any direction yet facilitates motion.

1.5.2 Force closure

If the articular surfaces of the lumbar spine, pelvic girdle, and hip were constantly and completely compressed, mobility would not be possible. The amount of force closure required depends on the individual's form closure and the magnitude of the load. The anatomical structures responsible for force closure are the ligaments, muscles, and fascia.

For every joint, there is a position called the close-packed, or self-locked, position in which there is maximum congruence of the articular surfaces and maximum tension of the major ligaments. In this position, the joint is under significant compression and the ability to resist shear forces is enhanced by the tension of the passive structures and increased friction between the articular surfaces (Vleeming et al 1990b, Snijders et al 1993a, b).

For the zygapophyseal joints of the lumbar spine this position is end-range extension, for the sacroiliac joints full nutation of the sacrum or posterior rotation of the innominate (Vleeming et al 1989a, b, van Wingerden et al 1993), and for the hip joint extension combined with abduction and internal rotation.

Studies have shown (Egund et al 1978, Lavignolle et al 1983, Sturesson et al 2000, Hungerford 2002) that nutation of the sacrum occurs bilaterally whenever the lumbopelvic spine is loaded. The amount of sacral nutation varies with the magnitude of the load. Full sacral nutation (self-locking or close-packing) occurs during forward and backward bending of the trunk (Sturesson et al 2000).

Counter-nutation of the sacrum, or anterior rotation of the innominate, is thought to be a relatively less stable position for the SIJ. The long dorsal ligament becomes taut during this motion. However, the other major ligaments (sacrotuberous, sacrospinous, and interosseus) are less tensed (Vleeming et al 1996).

The orientation of the capsule and the articular ligaments of the hip joint contribute to force closure of the hip during functional motions. Extension of the femur winds all of the extraarticular ligaments around the femoral neck and renders them taut.

The inferior band of the iliofemoral ligament is under the greatest tension in extension. Flexion of the femur unwinds the ligaments, and when combined with slight adduction, predisposes the femoral head to posterior dislocation if sufficient force is applied to the distal end of the femur (e.g., dashboard impact).

During lateral rotation of the femur, the iliotrochanteric band of the iliofemoral ligament and the pubofemoral ligament become taut while the ischiofemoral ligament becomes slack. Conversely, during medial rotation of the femur, the anterior ligaments become slack while the ischiofemoral ligament becomes taut (Hewitt et al 2002).

Abduction of the femur tenses the pubofemoral ligament and the inferior band of the iliofemoral ligament as well as the ischiofemoral ligament. At the end of abduction, the neck of the femur impactson to the acetabular rim, thus distorting and everting the labrum (Kapandji 1970).

In this manner, the acetabular labrum deepens the articular cavity (improving form closure), thus increasing stability without limiting mobility. Adduction results in tension of the iliotrochanteric band of the iliofemoral ligament while the others remain relatively slack.

Adduction of the flexed hip tightens the ischiofemoral ligament (Hewitt et al 2002). The ligamentum teres is under moderate tension in erect standing as well as during medial and lateral rotation of the femur.

Function would be significantly compromised if joints could only be stable in the close-packed position. Stability for load transfer is required throughout the entire range of motion and this is provided by the active, or neuromyofascial system.

Bergmark in 1989 proposed that muscles could be classified into two systems - a local and a global system. The local system pertains to those muscles essential for segmental or intrapelvic stabilization while the global system appears to be more responsible for regional stabilization (between the thorax and pelvis or pelvis and legs) (Bergmark 1989, Richardson et al 1999, Comerford & Mottram 2001). There is a significant neurophysiological difference in the timing of contraction of these two muscle systems. When loads are predictable, the local system contracts prior to the perturbation (in anticipation) regardless of the direction of movement (Hodges 1997, 2003, Hodges & Richardson 1997, Hodges et al 1999, Moseley et al 2002, 2003) whereas the global system contracts later and is direction-dependent (Radebold et al 2000, 2001, Hodges 2003). While some researchers have embraced this classification, others have not (Richardson et al 1999, Comerford & Mottram 2001); others have not (McGill 2002).

The research is still lacking which enables classification of all muscles according to this system and clinically it appears that parts of some muscles may belong to both systems. With respect to the lumbopelvic - hip region, the following muscles fit the criteria for classification as local stabilizers - the muscles of the pelvic floor (Constantinou & Govan 1982, Bo & Stein 1994, Sapsford et al 2001, Hodges 2003), the transversus abdominis (Hodges & Richardson 1997, Hodges 2003), the diaphragm (Hodges & Gandevia 2000a, b, Hodges 2003), and the deep fibers of multifidus (Moseley et al 2002, 2003). As research continues, more muscles will likely be added to this list. The deep (medial) fibers of psoas (Gibbons et al 2002), the medial fibers of quadrates lumborum (Bergmark 1989, McGill 2002), the lumbar parts of the lumbar iliocostalis and longissimus (Bergmark 1989), and the posterior fibers of the internal oblique (Bergmark 1989, O'Sullivan 2000)are some likely candidates.

1.5.3 Role of local muscle system

The function of the lumbopelvic local system is to stabilize the joints of the spine and pelvic girdle in preparation for (or in response to) the addition of extemalloads. This is achieved through several mechanisms, some of which include:

- Increasing the intraabdominal pressure (McGill & Norman 1987, Cresswell 1993, Hodges & Gandevia 2000a, b, Hodges et al 2001a, 2003b Hodges 2003)
- Increasing the tension of the thoracodorsal fascia (Cresswell 1993, Vleeming et a11995a, Willard 1997, Hodges 2003, Hodges et a12003b)
- Increasing the articular stiffness (Hodges et al 1997a, Richardson et al 2002, Hodges 2003)

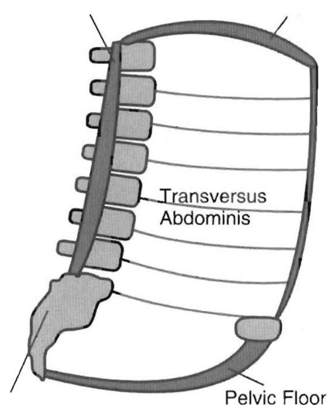

FIG. 8. *The local system of the lumbopelvic region consists of the muscles of the pelvic floor, the transverses abdominis, the diaphragm, and the deep fibers of multifidus.*

Research has shown (Constantinou & Govan 1982, Hodges 1997, 2003, Hodges & Gandevia 2000a, b, Sapsford et al 2001, Hungerford 2002, Moseley et al 2002, 2003) that when the central nervous system can predict the timing of the load, the local system is anticipatory when functioning optimally. In other words, these muscles should work at low levels at all times and increase their action before any further loading or motion occurs.

1.5.3.1 Transversus abdominis

Dr. Paul Hodges' first PhD focused on the role of transversus abdominis in healthy individuals and the response of this muscle in patients with low back pain (Hodges & Richardson 1996, 1997). He was able to show that transversus abdominis is an anticipatory muscle for stabilization of the low back and is recruited prior to the initiation of any movement of the upper or lower extremity.

He also showed that this anticipatory recruitment of transversus abdominis is absent or delayed in patients with low back pain. Dr. Paul Hodges has just completed his second PhD (2003: Neuromechanical control of the spine). This series of studies provides further information on how lumbopelvic stability is achieved. According to (Hodges 2003) a key finding from this research is that:

When the upper limbs were moved rapidly in response to a light, the anticipatory postural adjustment did not stiffen the trunk, but rather there was a consistent pattern of trunk motion that was specific to the direction of limb movement.

FIG. 9. *Contraction of the transversus abdominls is proposed to produce a force which acts on the ilia perpendicular to the sagittal plane*

Stability is achieved through motion, not rigidity. Small angular displacements of the vertebra preceded the limb movement and occurred in the opposite direction (preparatory movement) to the predicted movements of the segment (resultant movement). In other words, during rapid bilateral flexion of the upper limbs, a small amount of segmental extension occurred in the lumbar spine (preparatory movement) before the arms moved (flexed). After the arms flexed, the lumbar segments flexed (resultant movement) a small amount.

The opposite preparatory and resultant movements were noted during bilateral extension of the upper limbs. Transversus abdominis was the first trunk muscle recruited in all of these experiments yet did not render the trunk rigid. Hodges 2003, proposes that movement is used to dissipate or dampen the imposed internal and external forces which occur as a result of the perturbation. Therefore optimal stability requires mobility and a finely tuned motion control system.

In a study of patients with chronic low back pain, a timing delay or absence was found in which transverses abdominis failed to anticipate the initiation of arm and / or leg motion. Delayed activation of transversus abdominis means that the thoracodorsal fascia is not pretensed and the joints of the low back and pelvis are therefore not stiffened (compressed) in preparation for external loading al1d are potentially vulnerable to losing intrinsic stability.

1.5.3.2 Deep fibers of multifidius

Moseley has shown that the deep fibers of the multifidus muscle are also anticipatory for stabilization of the lumbar region and are recruited prior to the initiation of any movement of the upper extremity when the timing of the load is predictable (Moseley et al 2002). In contrast, the superficial and lateral fibers of the multifidus muscle were shown to be direction-dependent. In the pelvis, this muscle is contained between the dorsal aspect of the sacrum and the deep layers of the thoracodorsal fascia. When the deep fibers of the multifidus contract, the muscle can be felt to broaden or swell. As the deep fibers of multifidus broaden, they "pump up" the thoracodorsal fascia much like blowing air in to a balloon (Gracovetsky 1990, Vleeming et al 1995a).

Using the Doppler imaging system (Richardson et al 2002), noted that a co-contraction of multifid us and transversus abdominis increased the stiffness of the SIJ. Although multifidus is not oriented transversely, its contraction tenses the thoracodorsal fascia and it is likely this structure which imparts compression to the posterior pelvis. Several investigators have studied the response of multifidus in low back and pelvic pain patients and note that multifidus becomes inhibited and reduced in size in these individuals. The normal "pump-up" effect of multifidus on the thoracodorsal fascia, and therefore its ability to compress the pelvis, is lost when the size or function of this muscle is impaired.

Rehabilitation requires both retraining (Hides et al 1996, O'Sullivan et al 1997) and hypertrophy of the muscle (Danneels et al 2001) for the restoration of proper force closure of the lumbopelvic region. Together, multifidus and transversus abdominis (along with their fascia) form a corset of support for the lumbopelvic region the "circle of integrity."

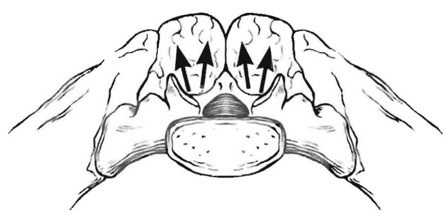

FIG. 10. *When the deep fibers of the multifidus contract, the muscle can be felt to broaden or swell (represented by the arrows in the deep layers of the muscle). This hydraulic amplifying mechanism "pumps up "the thoracodorsal fascia much like blowing air into a balloon*

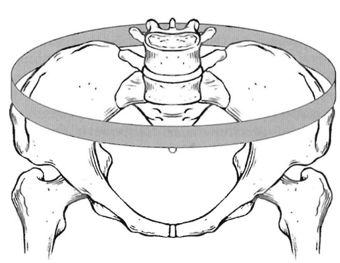

FIG. 11. *Together, multifidus and transversus abdominis form a corset of support for the lumbopelvic region, collectively called the "circle of integrity."*

1.5.3.3 Pelvic floor

The "roof and floor" of this local system (Fig. 8) are supported by the muscles of the pelvic floor and the respiratory diaphragm. The muscles of the pelvic floor play a critical role in both stabilization of the pelvic girdle and in the maintenance of urinary and fecal continence (Constantinou & Govan 1982, Bo & Stein 1994, Ashton-Miller et al 2001, Peschers et al 2001a, Sapsford et al 2001, Dietz et al 2003).

Constantinou & Govan (1982) measured the intraurethral and intrabladder pressures in healthy continent women during coughing and valsalva (bearing down) and found that during a cough the intraurethral pressure increases approximately 250 ms before any pressure increase is detected in the bladder. This suggests that the urethra anticipates the impending load during coughing. The increase in urethral pressure occurred simultaneously with the increase in bladder pressure during a valsalva (no urethralan ticipation). Constantinou & Govan suggest that the timing difference in pressure generation within the urethra and bladder during a cough versus a valsalva may be due to the contraction of the pelvic floor during a cough and relaxation of the pelvic floor during a Valsalva.

Sapsford et al (2001) investigated the co-activation pattern of the pelvic floor and the abdominals via needle electromyogram (EMG) for the abdominals and surface EMG for the pelvic floor. In two subjects, finewire needle EMG was used to detect activation of the right pubococcygeus through the lateral vaginal wall. They found that the abdominals contract in response to a pelvic floor contraction command and that the pelvic floor contracts in response to both a "hollowing" and "bracing" abdominal command. The results from this research suggest that the pelvic floor can be facilitated by co-activating the abdominals and vice versa. Constantinou & Govan's suggestion that there may be a reflex connection between the pelvic floor and the urethra is supported by this research.

There has been considcrdble debate regarding the function of psoas major. Although it has been variously argued to have functions associated with hip flexion, lumbar flexion and lateral flexion, more recently attention has been directed to differential functions of the posterior and anterior portions. In general, it is argued that the posterior fibres have a role in intervertebral compression, whereas the anterior fibres generate comprission and movement of the spine and hip (Bogduk et al 1992a). This has led to the proposal that the posterior fibres contribute to segmental control of the spine (Gibbons 2001), although part of the posterior aspect of the abdominal wall psoas has minimal contribution to Intra-abdominal pressure (IAP) generation (Williams et al 1989).

Psoas has been considered extensively in the clinical literature in LBP. The muscle is regarded as one that has a tendency to overactivity and tightness, and clinical techniques have been developed to stretch the muscle and reduce its activity (Janda 1978, 1986, Travell and Simons 1983). More recently, the argument that this muscle is really two separate muscles has been presented.

Bogduk et al (1992a) argued that the posterior fibres, which arise from the transverse processes, have a limited capacity to move the spine or hip but generate compression at the lumbar segments. In contrast, the anterior fibres make a larger contrbtion to movement. Therefore, the posterior fibres could have a mechanical contribution to the control of intervertebral motion (Gibbons 2001).

1.5.3.4 Diaphragm

The diaphragm is traditionally considered to be a respiratory muscle. (Hodges 2003, Hodges et al 1997a, b, Hodges & Gandevia 2000a, b) investigated the role of the diaphragm as a stabilizer of the trunk during perturbation studies involving rapid, single (Hodges et al 1997b, 2001c) and rapid, repetitive (Hodges & Gandevia 2000b, Hodges et al 2001c) shoulder flexion. They found that EMG activity in both the costal and crural portions of the diaphragm occurred simultaneously with the transversus abdominis and approximately 20 ms prior to any EMG activity noted in the deltoid. They also noted that the anticipatory activity of the diaphragm depends on the magnitude of the perturbation and occurred regardless of the phase of respiration in which the shoulder was rapidly

moved (Hodges et al 1997b). This research supports the classification of the diaphragm acting as a local stabilizer of the trunk in addition to its respiratory responsibilities.
Hodges & Gandevia (2000a, b) also noted that when loads to the trunk are sustained, the diaphragm responds tonically throughout the respiratory cycle for postural support of the trunk and simultaneously modulates this tonic activation to control the intrathoracic pressure necessary for breathing. An interesting pattern between the amplitude of activation of the diaphragm and the transversus abdominis was noted in the initial study (Hodges & Gandevia 2000a).

The amplitude of diaphragm EMC was higher in inspiration than expiration. The opposite pattern of activity modulation was found for both the right and left TrA (transversus abdominis). Similar to the diaphragm, TrA was active throughout the respiratory cycle and was modulated with respiration, but the amplitude of TrA EMC was higher during expiration.

When repetitive and sustained (10s) perturbation of the trunk was added to the experiment Hodges & Gandevia (2000b), another modulation of diaphragm activity was seen. There was a phasic modulation of activity which occurred at the frequency of the limb movement superimposed on the respiratory and tonic /postural activation.

Our data sugget that diaphragm EMG has three components; increased tonic activity, phasic modulation with respiration and phasic modulation with movement.

In a subsequent study (Hodges et al 200lc), the authors noted that the tonic function (as well as the phasic modulation associated with arm movement) of both the diaphragm and transversus abdominis was reduced or absent after only 60s of hypercapnia. Blaney & Sawyer (1997) measured the amplitude of descent of the diaphragm from functional residual capacity to maximal inspiration in subjects who were about to undergo upper abdominal surgery and found the average displacement of the crural portion to be 5.5 ± 1.1 cm preoperatively. No significant difference was noted between abdominal versus lateral costal expansion breathing patterns. Postoperatively, the amplitude of the diaphragm descent decreased to 2.0 ± 1.0 cm (58% decrease) and again no significant difference was noted between the two breathing patterns. However, the authors did note that when the subject was instructed just to take a deep breath, the amplitude of descent was much less and they concluded that the proprioceptive input from the therapist's hands can play a significant role in the excursion of the diaphragm.

Blaney et al (1997) subsequently measured diaphragmatic displacement during tidal breathing maneuvers (quiet breathing – not forced, not full) and noted that the excursion of the diaphragm varied with the pattern of breathing. They measured diaphragm displacement during upper chest, abdominal, and lateral costal breathing and found the mean amplitude to be 2.2, 3.1, and 2.4 cm respectively. Optimally, DeTroyer has found that quiet breathing should consist of 60% lateral costal expansion and 40% upper abdominal motion.

In conclusion, when the local system is functioning optimally, it provides anticipatory intersegmental stiffness of the joints of the lumbar spine (Hodges et al 2003b) and pelvis (Richardson et al 2002). This external force (force closure) augments the form closure (shape of the joint) and helps to prevent excessive shearing at the time of loading. This stiffness/compression occurs prior to the onset of any movement and prepares the low back and pelvis for additional loading from the global system. Simultaneously, the diaphragm maintains respiration while the pelvic floor assists in maintaining the position of the pelvic organs (continence) as load is transferred through the pelvis.

The lateral portion of quadratus lumborum, which spans the lumbar spine, belongs to the global system and is primarily involved in lateral bending. In contrast, the medial portion, which attaches directly to the lumbar vertebral transverse processes, is capable of providing segmental stability via its segmental attachments (McGill et al 1996), although it is unlikely to make a substantial contribution to lateral flexion (Bogduk 1997). McGill et al (1996) provided evidence that the quadratus lumborum plays a significant role in the stability of the spine.

Muscle activity was measured during a symmetrical bucket-holding task. Activity increased with increasing spinal compression provided through progressive axial loading. Further evidence for the general stabilizing role of the quadratus lumborum was provided by (Andersson et al 1996), who found that, unlike with the erector spinae (Kippers and Parker 1985), there was no electrical silence of the muscle in full forward flexion. These data clearly support the idea that this muscle is a powerful contributor to control of buckling forces. Intertestingly, in patients with LBP, overactivity, tightness and trigger points are often reported by clinicians (Travell and Simons 1983, Janda 1996). Treatment is focused on decreasing activity in the quadrates lumborum rather than increasing it with exercise.

1.5.4 Role of global muscle system

In the past, four slings of muscle systems which stabilize the pelvis regionally (between the thorax and legs) have been described by (Vleeming et al 1995a, b, Snijders et al 1993a). The posterior oblique sling (Fig. 12) contains connections between the latissimus dorsi and the gluteus maximus through the thoraco dorsal fascia. The anterior oblique sling (Fig. 13) contains connections between the external oblique, the anterior abdominal fascia, and the contralateral internal oblique abdominal muscle and adductors of the thigh. The longitudinal sling connects the peroneu, the biceps femoris, the sacrotuberous ligament, the deep lamina of the thoracodorsal fascia, and the erector spinae. The lateral sling contains the primary stabilizers for the hip joint, namely the gluteus medius / minim us and tensor fascia latae and the lateral stabilizers of the thoracopelvic region.

These muscle slings were initially classified to gain a better understanding of how local and global stability of the pelvis could be achieved by specific muscles. It is now recognized that, although individual muscles are important for regional stabilization as well as for mobility, it is critical to understand how they connect and function together. A muscle contraction produces a force that spreads beyond the origin and insertion of the active muscle. This force is transmitted to other muscles, tendons, fasciae, ligaments, capsules, and bones that lie both in series and in parallel to the active muscle. In this manner, forces are prod uced quite distant from the origin of the initial muscle contraction.

These integrated muscle systems produce slings of forces that assist in the transfer of load. Van Wingerden et al (2001) used the Doppler imaging system to analyze the effect of contraction of the biceps femoris, erector spinae, gluteus maximus, and latissiumus dorsi on compression of the SIJ. None of these muscles directly crosses the SIJ yet each was found to effect compression (increase stiffness) of the SIJ. The global system of muscles is essentially an integrated sling system, comprised of several muscles, which produces forces. A muscle may participate in more than one sling and the slings may overlap and interconnect depending on the task being demanded.

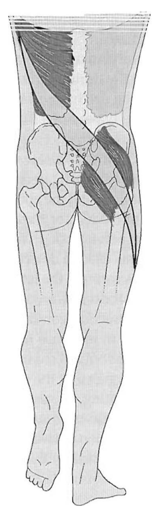

FIG. 12. *The posterior obliques ling of the global system includes the latissimus dorsi, gluteus maximus , and the intervening thoracodorsal fascia*

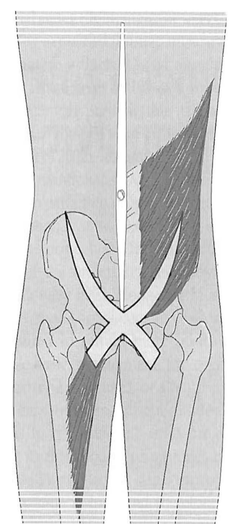

FIG. 13. *The anterior obliques ling of the global system includes the external oblique, the contralateral internal oblique, the adductors of the thigh, and the intervening anterior abdominal fascia*

The hypothesis is that the slings have no beginning or end but rather connect to assist in the transference of forces. It is possible that the slings are all part of one interconnected myofascial system and the particular sling (anterior oblique, posterior oblique, lateral, longitudinal), which is identified during any motion, is merely due to the activation of selective parts of the whole sling.

The identification and treatment of a specific muscle dysfunction (weakness, inappropriate recruitment, tightness) is important when restoring global stabilization and mobility (between the thorax and pelvis or between the pelvis and legs) and for understanding why parts of a sling may be inextensible (tight) or too flexible (lacking in supp ort).

1.5.5 Motor control

Motor control pertains to patterning of muscle activation (Hodges & Richardson 1996, Hodges 2000, O'Sullivan et al 1997, Richardson et a1 1999, O'Sullivan 2000, Comerford & Mottram 2001, Danneels et al 2001, Moseley et al 2002, Hodges 2003), in other words, the timing of specific muscle action and inaction. Efficient movement requires coordinated muscle action, such that stability is ensured while motion is controlled and not restrained (Hodges et al 2001b, Hodges 2003). With respect to the lumbopelvic region, it is the coordinated action between the local and global systems that ensures stability without rigidity of posture and without episodes of collapse. Exercises that focus on sequencing muscle activation are necessary for restoring motor control.

1.5.6 Emotions

Emotional states can play a significant role in human function, including the function of the neuromusculoskeletal system. Many chronic pelvic pain patients present with traumatized life experiences in addition to their functional complaints. Several of these patients adopt motor patterns indicative of defensive posturing which suggest a negative past experience.

A negative emotional state leads to further stress. Stress is a normal response intended to energize our system for quick flight and fight reactions. When this response is sustained, high levels of epinephrine (adrenaline) and cortisol remain in the system (Holstege et al 1996), in part due to circulating stressrelated neuropeptides (Sapolsky & Spencer 1997, Sapolsky et al 1997) which are released in anticipation of defensive or offensive behavior.

Emotional states (fight, flight, or freeze reactions) are physically expressed through muscle action and, when sustained, influence basic muscle tone and patterning (Holstege et al 1996). If the muscles of the pelvis become hypertonic, this state will increase compression of the SIJs (van Wingerden et al 2001, Richardson et al 2002). It is important to understand the patient's emotional state since the detrimental motor pattern can often only be changed by affecting the emotional state.

Also, it can be as simple as restoring hope through education and awareness of the underlying mechanical problem (Butler & Moseley 2003, Hodges & Moseley 2003). Other times, professional cognitive-behavioral therapy is required to retrain more positive thought patterns. A basic requirement for cognitive and physical learning is focused, or attentive, training in other words, not being absent-minded. Teaching individuals to be "mindful" or aware of what is happening in their body during times of physical and / or emotional loading can reduce sustained, unnecessary muscle tone and therefore joint compression (Murphy 1992).

Chapter II

2. Goals

The main purposes of the thesis are:

- Classify and define LBP related to lumbopelvic instability in body function and body structure.
- Describe evedince-based spinal stability concept, by presenting group of concepts considering the stabilization system of the spine.
- Provide adescribtion of the main principles functions and dysfunctions of lumbopelvic-hip region.
- Describe the biomechanics of lumboplevic-hip related to the LBP includiong the kinematics of lumbar, pelvic girdle and hip joint.

Chapter III

3. Methodology

The diploma thesis will be written in the form of a literature review.

3.1. Population

No strict criteria have been established for the populations investigated in the individual studies to be reviewed. For each article/ study, however, the following points about the population researched will be noted and judged for comparison purposes. The following criteria about the population studied will be noted:

- Male, Female
- Age: 18 to 75
- Activity level:
    - Professional athlete
    - Non-Professional athlete
    - Non-Sport
- Health state:
    - Non- Injured
    - Without damage of soft tissues
    - Non-Operational
    - Non-Neuro/Internal problems

3.2 Measurements

- Static posture
- Dynamic movements
- Stabilizer pressure biofeed back
- X-ray
- Electromyography (EMG)
- Ultrasound
- Functional tests

3.3. Method of data gathering

Articles for analysis will be gathered from available internet resources. Attempt will be made to gather data for general discussion from so called “grey literature.” The following criteria were used to include and exclude articles from the main analysis:

Inclusion criteria

- Search in following databases/ search engines: EMBASE, EBSCO, Spine Journal, Ovid, ProQuest, Medline and Wiley Interscience
- Search with a combination of the following words: low back pain, lumbopelvic, hip, lumbar, insufficient, spine, stability
- Published in the year 1990 or later

Exclusion criteria

- Number of subjects: less than 10, except case reports
- Written in language other than English, Arabic
- Subjects with diseases or injuries that can have impact on the cause of low back pain.
- Poorly written scientific articles
- Experiment was not done on live humans (on animals, in vitro, on cadavers etc.)

3.4. Analysis

The articles accepted for the analysis, according to the criteria above, will be grouped into the following topics:

- Overview to low back pain related to spinal stability
- Spinal stability concept
- Normal function of spinal stabilization system: the passive (ligamentous) subsystem, the active (musculotendenous) subsystem and the neural control subsystem
- Dysfunction of spinal stabilization system

- Principles functions of lumbopelvic-hip region: form closure. force closure, role of local muscle system, role of global muscle system, motor control and emotions
- Biomechanics of lumbopelvic-hip region: Kinematics of lumbar, Kinematics of pelvic girdle, kinematics hip joint

3.5. Scope of Validity

3.5.1 Restrictions

This project is based on article reviews, the populations presented are limited to the ones introduced in the analyzed articles.

3.5.2 Limitations

The collections of articles were made from limited available resources online. The analysis did also include articles published as solely hard copied material and gray literature.

3.5.3 Expenditure requirements

No main expenditures have been identified as all resources were accessed online. This project has not received any founding or grants.

Chapter IV

4. Biomechanics of lumbopelvic-hip region

The primary function of the lower quadrant is to provide stable move simultaneously with the upper extremity which then can transfer load. Together, the trunk and the lower extremities have the potential for multidirectional movement with a minimum of energy expenditure (Abitbol1995, 1997, McNeill 1995, 1997). Neuromusculoskeletal harmony is essential for optimal lumbopelvic-hip function. In (1911), Meisenbach stated that:

When the trunk is moved to one side quickly there are direct opposing forces of the lumbar and spinal muscles against the pelvic and leg muscles. Normally these work in harmony and are resisted by the strong pelvic ligaments and fascia to a certain extent. If the harmony of these muscles is disturbed from some cause or another, or if the ligamentus support is weakened, other points of fixation must necessary yield.

4.1 Kinematics of lumbar

In mechanical terms, the lumbar vertebrae have the potential for 6 degree of freedom (Levin 1997) (Fig. 14). Clinically, the lumbar spine appears to exhibit four degrees of freedom of motion: flexion, extension, rotation/sideflexion right, and rotation/sideflexion left (Pearcy & Tibrewal 1984, Vicenzino & Twomey 1993, Bogduk 1997). Throughout the spine, flexion/extension is an integral part of forward/backward bending of the head or trunk while rotation/sideflexion occurs during any other motion.

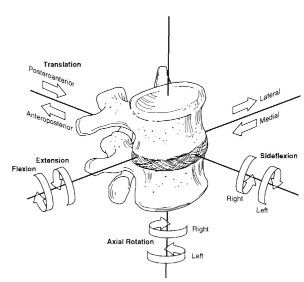

FIG. 14. *In mechanical terms, there are 6 degrees of motion of the lumbar vertebrae.*

Flexion/Extension: In the lumbar spine, the coronal axis is dynamic rather than static and moves forward with flexion such that flexion couples with a small degree (1-3mm) of anterior translation (Figs 15). (White & Panjabi 1978, Gracovetsky et al 1981, Gracovetsky & Farfan 1986, Bogduk 1997)

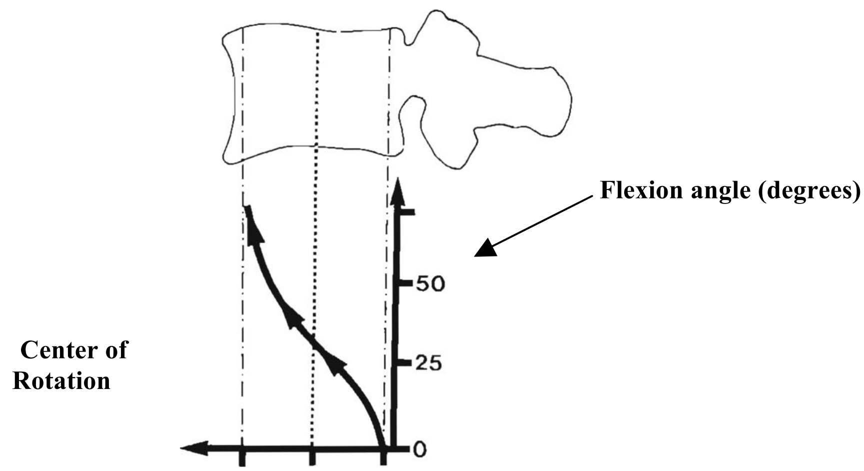

FIG. 15. *The coronal axis for flexion/extension moves anteriorly with increasing degrees of flexion*

Conversely, extension couples with posterior translation during backward bending of the trunk. At the zygapophyseal joints, the arthrokinematics of flexion and extension are impure swings. During flexion, the inferior articular processes of the superior vertebra glide superiorly and anteriorly along the superior articular processes of the inferior vertebra/sacrum (Bogduk 1997). During extension, the inferior articular processes of the superior vertebra glide inferiorly and posteriorly along the superior articular processes of the inferior vertebra / sacrum. The total amplitude of this glide is about 5-7 mm.

Rotation/Sideflexion: Motion coupling of the vertebral column during rotation or lateral bending of the trunk was first recorded by Lovett in 1903. He noted that a flexible rod bent in one plane could not bend in another without twisting. The direction of this motion coupling has been a controversial issue.

In 1984, Pearcy & Tibrewal reported on a threedimensional radiographic study of lumbar motion during rotation and lateral bending of 10 men under 30 years of age. Their findings of coupled motion (Fig. 16) were consistent with those of (Gracovetsky & Farfan 1986) except at the lumbosacral junction where lateral bending coupled with ipsi-lateral axial rotation. L4-L5 was noted to be transitional and followed the movement pattern of either L3-L4 or L5-Sl. This study did not investigate the coupling of motion when lateral bending was introduced from a position of flexion or extension.

According to Bogduk (1997), 3° of pure axial rotation of a lumbar motion segment is possible. At this point, all of the fibers of the annulus fibrosus that are aligned in the direction of the rotation are under stress, the sagittal component of the contralateral zygapophyseal joint is compressed, and the ipsilateral zygapophyseal joint capsule is tensed. The axis of motion is vertical through the posterior part of the vertebral body. After 3° of rotation, the axis shifts to the impacted zygapophyseal joint and the upper vertebra pivots about this new axis. The vertebral body swings posterolaterally, imposing a lateral translation force on the intervertebral disk. The impacted inferior articular process swings backwards and medially, further stretching the capsule and ligaments. Further rotation can result in failure of any of the stressed or compressed components.

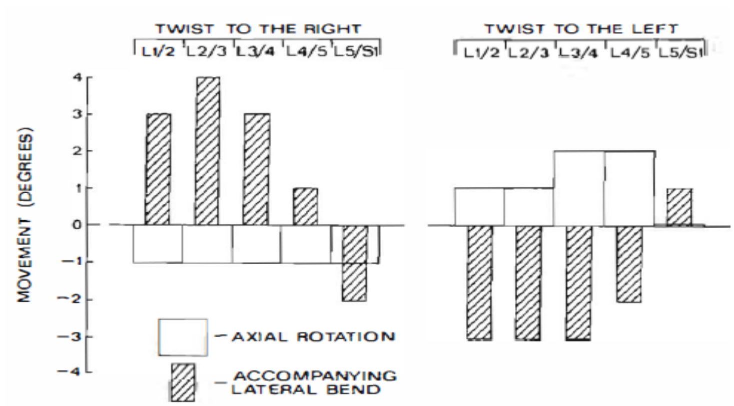

FIG. 16. *Findings of coupled motion of rotation and lateral bending in the lumbar spine. At the lumbosacral junction, lateral bending occurs in the same direction as the induced rotation*

According to Bogduk (1997), 35% of the resistance to torsion is provided by the intervertebral disk and 65% by the posterior elements of the neural arch. Bogduk (1997) supports Pearcy & Tibrewal's (1984) model of motion coupling and concurs that for the upper three segments axial rotation is accompanied by contralateral sideflexion. This motion is unidirectional about an oblique axis and also involves slight flexion or extension of the segment (Fig. 17). He agrees that at L5-S1 the pattern tends to be ipsi-lateral and that L4-L5 is variable. In addition, he notes that individual variation exists and resists any rules for segmental motion patterning.

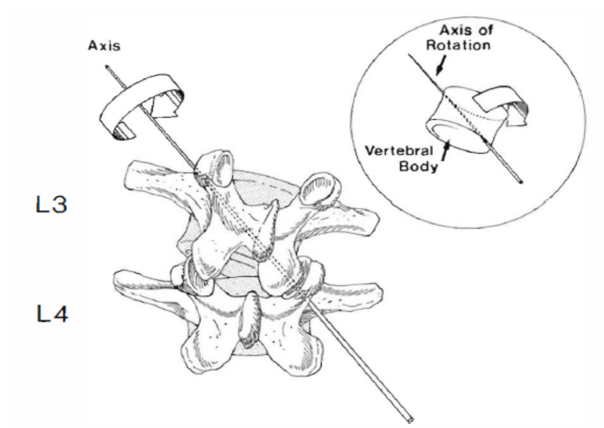

FIG. 17. *Left rotation of the L3-L4 joint complex couples with contralateral sideflexion*

Vicenzino & Twomey (1993) investigated the conjunct rotation which occurred during lateral bending of the lumbar spine and noted that in 64% of their specimens no conjunct rotation occurred at L5-Sl. This coupling of motion was consistent when the segment was side flexed from a flexed, neutral, or extended position. Above L5-S1 an interesting pattern emerged. In extension, Ll-L2 and L3-L4 rotated opposite to the direction of sideflexion. In flexion, L1-L2 and L3-L4 rotated in the same direction as the sideflexion. Conversely, in extension, L2-L3 and L4-L5 rotated in the same direction as the sideflexion and in flexion L2-L3 and L4-L5 rotated in the opposite direction. The conclusion from this study was that the coupling of motion in the lumbar spine was indeed complex.

The biomechanics of the lumbar spine have been shown (Farfan 1973, Kirkaldy-Willis et al 1978, White & Panjabi 1978, Kirkaldy- Willis 1983, Gilmore 1986, Grieve 1986, Stokes 1986, Twomey & Taylor 1986) to change with both age and degeneration. The instantaneous center of rotation for flexion/ extension and/or rotation/ sideflexion can be significantly displaced with degeneration, resulting in excessive posteroanterior and/or lateral translation during physiological motion of the trunk (White & Panjabi 1978, Stokes 1986)

Even if the biomechanics of the lumbosacral junction were confirmed and conclusive, the potential for altered biomechanics to exist is high, rendering "perceptive clinical observation of a patient as the most direct way to assess spine motion clinically, despite its lack of objectivity" (Stokes 1986).

4.2 Kinematics of pelvic girdle

Mobility of the sacroiliac joint (SIJ) has been recognized since the seventeenth century. Since the middle of the nineteenth century, both postmortem and in vivo studies have been done in an attempt to clarify the movements of the SIJs and the pubic symphysis and the axes about which these movements occur (Meyer 1878, Goldthwait & Osgood 1905, Albee 1909, Sashin 1930, Weisl 1954, 1955, Colachis et al 1963, Egund et al 1978, Wilder et al 1980, Lavignolle et al 1983, Walheim & Selvik 1984, Miller et al 1987, Sturesson et al 1989, 2000, Vleeming et al 1990a, b, Kissling & Jacob 1997, Sturesson 1997, Hungerford et al 2001, Hungerford 2002).

The investigative methods include: manual manipulation of the SIJ both at surgery (Jarcho 1929, Chamberlain 1930, Lavignolle et al 1983); X-ray analysis in various postures of the trunk and lower extremity (Albee 1909, Brooke 1924); roentgen stereophotogrammetric and stereoradiographic imaging after the insertion of tantalum balls into the innominate and sacrum (Egund et al 1978, Walheim & Selvik 1984, Sturesson et al 1989, 2000, Sturesson 1997); and after the attachment of surface markers to the femur, sacrum, and innominate (Hungerford et al 2001, Hungerford 2002), inclinometer measurements in various postures of the trunk and lower extremity, after the insertion of Kirschner wires into the innominate and sacrum (Pitkin & Pheasant 1936, Colachis et al 1963, Jacob & Kissling 1995, Kissling & Jacob 1997), and computerized analysis using a Metrecom skeletal analysis system (Smidt 1995).

Clinical theories (DonTigny 1985, 1990, 1997, Hesch et al 1992, Lee 1992, 1999, Hesch 1997) have also contributed significantly towards the research in this region. The results of these studies have led to proposals concerning both function and dysfunction of the pelvic girdle. The following section will detail the current status of the biomechanics of the pelvic girdle.

Motion of the pelvic girdle as a unit can occur in all three body planes: anterior and posterior pelvic tilt in the sagittal plane, lateral tilt in the coronal plane, and axial rotation in the transverse plane. A combination of all of these motions occurs during the normal gait cycle (Greenman 1990, 1997). In addition, motion occurs within the pelvis. While mobility of the SIJ is small, movement has been shown to occur (Walheim & Selvik 1984, Miller et al 1987, Sturesson et al 1989, 2000, Sturesson 1997, Hungerford et al 2001, Hungerford 2002). In the past, the quantity of motion available at the SIJ has been debated. In 1983, Lavignolle et al reported 10-12° of posterior rotation of the innominate (coupled with 6mm of anterior translation), and 2° of anterior rotation (coupled with 8mm of anterior translation), in an in vivo study of two women and three men under 25 years of age. This study was conducted in the non-weight-bearing position and Vleeming note that this is probably a significant factor in the quantity of motion reported. Sturesson (1989, 2000) used roentgen stereophotogrammetric analysis (RSA) to investigate SIJ mobility in 21 women from 19 to 45 years of age and four men from 18 to 45 years of age. They found only 2S of innominate rotation (coupled with 0.5-1.6mm of translation). This in vivo study was conducted in the weight-bearing position Sturesson et al (2000) felt that the other authors (Weisl 1954, 1955, Colachis et al 1963, Lavignolle et al 1983) had overestimated the mobility of the SIJ.

Jacob & Kissling's (1995) findings of SIJ mobility using the RSA technique supported those of Sturesson et al (1989, 2000). The average values for rotation and translation were low, being 1.8° of rotation (coupled with 0.7mm of translation) for the men and 1.9° of rotation (coupled with 0.9mm translation) for the women.

No statistical differences were noted for either age or gender. They postulated that more than 6° of rotation and 2 mm of translation should be considered pathologic (Jacob & Kissling 1995).

In 1995, Buyruk et al (1995a, b) established that the Doppler imaging system could be used to measure stiffness of the SIJ. This research has recently been repeated and confirmed by Leonie Damen et al (2002a). Doppler imaging of vibrations across the SIJ has shown (Buyruk et a1 1995a, b, 1997, 1999, Damen et a1 2002a) that stiffness of the SII is variable between subjects and therefore the range of motion is potentially variable. This research has also revealed that stiffness of the SIJ is symmetric when the left and right sides are compared in subjects without pelvic pain and asymmetric in subjects with pelvic pain. These studies will be discussed in greater depth later. In conclusion, we know that the SIJ are capable of a small amount of both angular (1-40) and translatoric motion (1-3mm), that the amplitude of this motion is variable between subjects; however, within one subject it should be symmetric between sides.

Nutation/Counternutation of the Sacrum: Nutation and countenutation are osteokinematic terms that describe how the sacrum moves relative to the innominates regardless of how the pelvic girdle is moving relative to the lumbar spine and femora. Nutation of the sacrum occurs when the sacral promontory moves forward into the pelvis about a coronal axis through the interosseous ligament (Fig. 18). Conversely, countemutation of the sacrum occurs when the sacral promontory moves backward about this coronal axis (Fig. 19). The sacrum is countemutated in supine lying (Sturesson et al 2000) and nutates in sitting or standing (Sturesson et al 2000). In other words, whenever an individual is vertical, the sacrum is nutated relative to the innominates. The amount of sacral nutation depends on how the individual is sitting or standing. In an optimal posture, the sacrum should be suspended between the two innominates in slight nutation but not completely nutated (Levin 1997).

During the initial stages of forward or backward bending, the sacrum completely nutates between the innominates and should remain there throughout the full range of motion. On returning to standing, the sacrum remains nutated between the innominates until the erect posture is reached. At this point, the sacrum counternutates slightly (remaining relatively nutated) to become suspended once again between the two innominates.

When an individual stands in a collapsed posture (excessive kypholordosis or sway back), the sacrum can be completely nutated between the innominates. No further nutation will occur during forward or backward bending since the total available range of motion has been exhausted.

When an individual sits in a collapsed posture (slouched), the sacrum can be completely counternutated (forced by weight bearing through the coccyx).

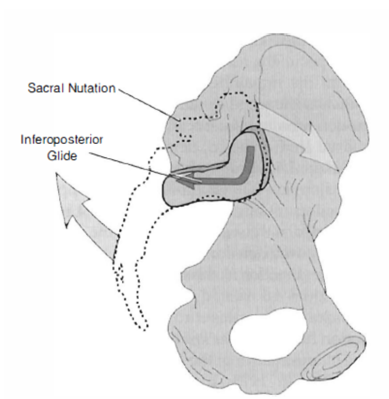

FIG. 18. *When the sacrum nutates, its articular Surface glides inferoposteriorly relative to the Innominate*

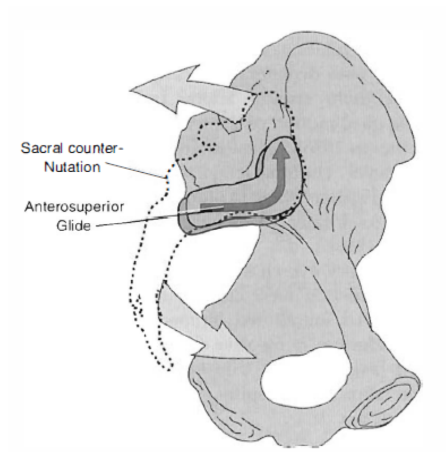

FIG. 19. *When the sacrum counternutates,its articular surface glides anterosuperiorly relative to the innominate*

Arthrokinematically, when the sacrum nutates relative to the innominate, a linear motion or translation between the two joint surfaces can occur. To date, there have been no studies to valida te the following arthrokinematics proposed to occur when the sacrum nutates relative to the innominate. During nutation, the proposal is that the the sacrum glides inferiorly down the short arm (S1) and posteriorly along the long arm (S2, S3) of the articular surface (Fig. 18). The amplitude of this translation is extremely small yet can be palpated. This motion is resisted by the wedge shape of the sacrum, the ridges and depressions of the articular surface, the friction coefficient of the joint surface and the integrity of the interosseous and sacrotuberous ligaments (Vleeming et al 1990a, b). This is the close-packed or selfbraced position of the SIJ - the most stable position for transferring intermittent, high loads. The interosseous and sacrotuberous ligaments are supported during nutation by the muscles which not only insert into them but compress the pelvic girdle transversely.

During counternutation, it is proposed that the sacrum glides anteriorly along the long arm and superiorly up the short arm (Fig. 19). This motion is resisted by the long dorsal sacroiliac ligament. This ligament is supported by the contraction of the multifidus which acts to nutate the sacrum. The multifidus and levator ani appear to act as a force couple to control sacral nutation/ counternutation.

Flexion/Extension of the Coccyx: Bo et al (2001) used MRI to investigate the function of the pelvic floor muscles and in this study noted that a contraction of the pelvic floor caused the coccyx to move in a ventral and cranial direction (flexion). During a Valsalva, or straining, they noted that the coccyx moved caudal and dorsal (extension).

Posterior Rotation of the innominate: Posterior rotation of the innominate is an osteokinematic term used to describe motion of the innominate relative to the sacrum and occurs about a coronal axis through the interosseous ligament of the SIJ. Using reflective surface markers on 15 bony landmarks of the femur, innominate, and sacrum and a sophisticated imaging system (six-camera Expert vision motion analysis hires 5.0 system), Hungerford (2002) noted that when an individual transferred weight through one leg and flexed the contralateral femur (Fig. 20.), the supporting innominate (weightbearing side) either posteriorly rotated or remained posteriorly rotated relative to the sacrum (sacrum is therefore relatively nutated). The SIJ is thus closepacked in preparation for load transfer. The nonweight- bearing innominate (side of hip flexion) also posteriorly rotated relative to the sacrum during this motion. Sturesson et al (2000) initially reported this osteokinematic pattern of intrapelvic motion during one-leg standing and this research confirms their findings. Hungerford also described a conjunct osteokinematic motion which occurred in association with posterior rotation of the innominate. On both the non-weight-bearing and weight-bearing sides, posterior rotation of the innominate was associated with sideflexion and rotation of the innominate. Sideflexion and rotation of the innominate were coupled in a countralatera l sense, although some variability was noted.

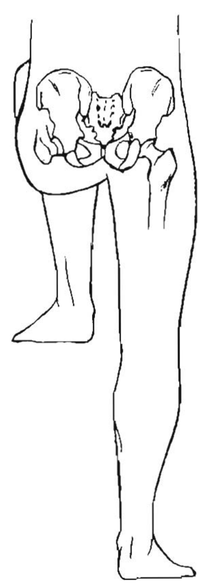

FIG. 20. *The one-leg standing test (Gillet): the indivi dual transfers weight through one leg and flexes the contralateral hip joint to approximately 90*

Hungerford also investigated the translatoric motion (arthrokinematics) between the innominate and sacrum during posterior rotation of the innominate on both the non-weight-bearing and weight bearing sides. On the weight-bearing side, the relative translatoric glide was posterior and superior relative to the sacrum. Concurrently, a medial translation was noted, which may reflect increased articular compression during loading. In other words, when the pelvic girdle is self-braced and compressed by the passive and active elements, the direction of the translation is no t as predicted (Lee 1999). Posterior and superior translation of the articular surface of the innominate relative to the sacrum would effectively "lock in" the SIJ similar to the engagement of gears in a bicycle. Motion would be prevented and stability ensured for load transfer when the articular surfaces engage in this manner.

Anterior Rotation of the innominate: Anterior rotation of the innominate is an osteokinematic term used to describe motion of the innominate relative to the sacrum and occurs about a coronal axis through the interosseous ligament of the SIJ. Hungerford did not investigate anterior rotation of the innomina te in healthy subjec ts; consequently the following is still a proposal.

In health, anterior rotation of the innominate occurs during extension of the freely swinging leg. When the innominate anteriorly rota tes, it glides inferiorly down the short arm and posteriorly along the long arm of the SIJ.

In conclusion, we now know that in nonweight- bearing an arthrokinematic glide between the innominate and the sacrum occurs during posterior rotation of the innominate and is physiological (i.e., follows the articular surfaces). In weigh tbearing, the close-packing of the SIJ precludes this physiological glide. The rest is still hypothesis. Sacral nutation produces the same rela tive arthrokinematic glide as posterior ro tation of the innominate (inferoposterior motion of the sacrum is the same as anterosuperior motion of the innominate); sacral counternutation produces the same arthrokinematic glide as anterior rotation of the innominate (anterosuperior motion of the sacrum is the same as inferoposterior motion of the innominate).

4.3 Kinematics of hip joint

The femur articulates with the innominate via a ball-and-socket joint, the hip, which is capable of circumductive motion. The hip is classified as an unmodified ovoid joint and in mechanical terms is capable of 12 degrees of freedom of motion along and about three perpendicular axes. This classification does not account for the anatomical factors which influence the coupling of motion which actually occurs at the joint.

Osteokinematically, flexion / extension occurs when the femur rotates about a coronal axis through the center of the femoral head and neck. Although variable, approximately 100° of femoral flexion is possible, following which motion of the SIJ and intervertebral joint occurs to allow the anterior thigh to approximate the chest (Williams 1995). Approximately 20° of femoral extension is possible (Kapandji 1970). When rotation of the femoral head occurs purely about this axis (i.e., without conjoined abduction/ adduction or medial/ lateral rotation), the motion is arthrokinematically described as a pure spin.

Abduction/adduction is an osteokinematic term used when the femur rotates about a sagittal axis through the center of the femoral head. Approximately 45° of femoral abduction and 30° of femoral adduction are possible, following which the pelvic girdle laterally tilts beneath the vertebral column (Kapandji 1970).

When the femur rotates purely about this sagittal axis, the head of the femur arthrokinematically transcribes a superoinferior chord within the acetabulum (i.e., the shortest distance between two points); therefore this motion is described as a pure swing.

Medial/lateral rotation is an osteokinematic term used when the femur rotates about a longitudinal axis. The location of this axis depends on whether the foot is fixed on the ground. When the pelvic girdle rotates about a firmly planted foot, the longitudinal axis of rotation runs from the center of the femoral head through to the lateral femoral condyle. When the foot is off the ground, the femur can rotate about a variety of longitudinal a xes, all of which pass through the femoral head and the foot (Williams 1995).

Approximately 30-40° of medial rotation and 60° of lateral rotation are possible (Kapandji 1970). Pure femoral rotation about this axis causes the femoral head arthrokinematically to transcribe an anteroposterior chord within the acetabulum and this motion is described as a pure swing.

Functionally, movement of the femur relative to the innominate does not produce pure arthrokinematic motion. Rather, combinations of movement are the norm. The habitual pattern of motion for the non-weight-bearing lower extremity is a combination of flexion, abduction, and lateral rotation and extension, adduction, and medial rotation. Arthrokinematically, both motions are impure swings. The close-pack position (most stable) of the hip is extension, abduction, and internal rotation.

Chapter V

5. Discussion

For modern society LBP is an expensive disease. The yearly prevalence varies from 15-20% in the USA to 25-40% in the European countries, and the lifetime prevalence is as high as 60-90% (Van Tulder 1996).

The models used to understand and treat LBP are generally based on desprective anatomy, such as spine, pelvis and lower limbs are primarily based on bony anatomy. Functional anatomy of the locomotor system, attempts to explain how bones, ligaments and muscles operates as a system. Consequently the use of desprective anatomy can be misleading to the main reason of the LBP (Vleeming et al 1995a).

A primary function of the pelvis is to transfer the loads generated by body weight and gravity during standing, walking, sitting and other functional tasks. How well this load is managed dictates how efficient function will be. The word 'stability' is often used to describe effective load transfer and requires optimal function of three systems: the passive (form closure), active (force closure) and control (motor control) (Panjabi 1992). Collectively these systems produce approximation of the joint surfaces (Snijders & Vleeming 1993a, b). The amount of approximation required is variable and difficult to quantify since it depends on an individual's structure (form closure) and the forces they need to control (force closure). The following definition of joint stability comes from the European guidelines on the diagnosis and treatment of pelvic girdle pain (Vleeming et al 2004).

"The effective accommodation of the joints to each specific load demand through an adequately tailored joint compression, as a function of gravity, coordinated muscle and ligament forces, to produce effective joint reaction forces under changing conditions. Optimal stability is achieved when the balance between performance (the level of stability) and effort is optimized to economize the use of energy. Non-optimal joint stability implicates altered laxity/stiffness values leading to increased joint translations

resulting in a new joint position and/or exaggerated/reduced joint compression, with a disturbed performance/effort ratio.

Based on this definition, the analysis of pelvic girdle function will require tests for excessive/reduced joint compression (mobility) as well as tests for motion control of the joints (sacroiliac (SIJ) and pubic symphysis) during functional tasks (one leg standing, active straight leg raise). Motion control of the joints requires the timely activation of various muscle groups such that the co-activation pattern occurs at minimal cost (minimal compression or tension loading and the least amount of effort) to the musculoskeletal system. Analysis of neuromuscular function will require tests for both motor control (timing of muscle activation) and muscular capacity (strength and endurance) since both are required for intersegmental or intrapelvic control, regional control (between thorax and pelvis, pelvis and legs) as well as the maintenance of whole body equilibrium during functional tasks. Treatment protocols should include techniques to reduce joint compression where necessary, exercises to increase joint compression where and when necessary and education to foster understanding of both the mechanical and emotional components of the patient's experience (Vleeming A, Albert H B, van der Helm F C T, Lee D, Ostgaard H C, Stuge B, Sturesson B).

For many decades, it was thought that the SIJ was immobile due to its anatomy. It is now known that mobility of the SIJ is not only possible (Egund et al 1978, Hungerford et al 2004, Lavignolle et al 1983), but essential for shock absorption during weight bearing activities and is maintained throughout life (Vleeming et al 1992a). The quantity of motion is small (both for angular and translatoric motion) and variable between individuals (Kissling & Jacob 1997).

The passive system (joint/ligaments) is analysed by comparing the amplitude and symmetry of motion between the innominate and sacrum (Lee 2004, Lee & Lee 2004)). The SIJ is then passively taken into the close-packed position (the position where there is maximum congruence of the joint surfaces and tension of the articular ligaments) which for the SIJ is sacral nutation/posterior rotation of the innominate) and the translations are repeated. When the ligaments are intact and healthy, no translation of the joint should occur in this close-packed, stable position.

In addition, this test should be pain free. If there is increased motion when the SIJ is in a neutral position and this translation persists in the close-packed position, this suggests that the ligaments have been stretched and a deficit in the passive system is implicated. This test often reproduces SIJ ligamentous pain. If there is increased motion when the SIJ is in a neutral position and no translation occurs when the joint is in the close-packed position, this suggests that the force closure or motor control system is impaired and that there is insufficient (or at least asymmetric) compression of the SIJ in neutral (Lee 2004)

Function would be significantly compromised if joints could only be stable in the close packed (self-locked or self-braced) position. Stability for load transfer is required throughout the entire range of motion and is provided by the active system (directed by the control system) when the joint is not in the close packed position. Optimal force closure of the pelvic girdle requires just the right amount of force being applied at just the right time (Hodges 2003). This in turn requires a certain capacity (strength/endurance) of the muscular system as well as a finely tuned motor control system, one that is able to predict the timing of the load and to prepare the system appropriately. The amount of compression needed depends on the individual's form closure and the loading conditions (speed, duration, magnitude). Therefore there are multiple optimal strategies possible, some for low loading tasks and others for high loading tasks. The compression, or force closure, is produced by an integrated action and reaction between the muscle systems, their fascial and ligamentous connections, and gravity. The timing, pattern and amplitude of the muscular contractions depend on an appropriate efferent response of both the central and peripheral nervous systems which in turn rely on appropriate afferent input from the joints, ligaments, fascia and muscles (Vleeming et al 1992a). It is indeed a complex system, often difficult to study, yet when one returns to the definition of joint stability (the ability to transfer loads with the least amount of effort which controls motion of the joints) not difficult to assess or treat.

A healthy, integrated neuromyofascial system ensures that loads are effectively transferred through the joints while mobility is maintained, continence is preserved and respiration supported. Non-optimal strategies result in loss of motion control (excessive shearing or translation) often associated with giving way, and/or excessive bracing (rigidity) of the hips, low back and/or rib cage. These strategies often create an excessive increase in the intra-abdominal pressure (Thompson et al 2004) which can compromise urinary and/or fecal continence. In addition, non-optimal respiratory patterns, rate and rhythm can develop. Often, patients with failed load transfer through the pelvic girdle present with inappropriate force closure in that certain muscles become overactive while others remain inactive, delayed or asymmetric in their recruitment (Hungerford et al 2003). These alterations in motor control must be considered during assessment because if altered, the system is not prepared for the loads which reach it and repetitive strains of the passive soft tissues can result. In particular, the recent evidence regarding the role of transverses abdominis, the deep fibres of the lumbar multifidus and the pelvic floor muscles suggests that they be singled out.

Although it does not cross the SIJ directly, transversus abdominis (TrA) can impact stiffness of the pelvis through its direct anterior attachments to the ilium as well as its attachments to the middle layer and the deep lamina of the posterior layer of the thoracodorsal fascia (Barker et al 2004). Richardson et al (2002) suggest that contraction of the TrA produces a force which acts on the ilia perpendicular to the sagittal plane (i.e. approximates the ilia anteriorly). In a study of patients with chronic low back pain, a timing delay was found in which TrA failed to anticipate the initiation of arm and/or leg motion (Hodges & Richardson 1996). This delayed activation of TrA could imply that the thoracodorsal fascia is not sufficiently pretensed, hence the pelvis not optimally compressed, in preparation for external loading leaving it potentially vulnerable to the loss of intrinsic stability during functional tasks.

Three other studies have shown altered activation in TrA in subjects with longstanding groin pain (Cowan et al 2004), low back pain (Ferreira et al 2004) and pelvic girdle pain (Hungerford et al 2003).

Hides et al (1994, 1996), Danneels et al (2000) and Moseley et al (2002) have studied the response of multifidus (deep, superficial and lateral fibres) in low back and pelvic girdle pain patients and note that the deep fibres of multifidus (dMF) become inhibited and reduced in size in these individuals. It is hypothesized that the normal "pump-up" effect of the dMF on the thoracodorsal fascia, and therefore its ability to compress the pelvis posteriorly, is lost when the size or function of this muscle is impaired.

Using the Doppler imaging system, Richardson et al (2002) noted that when the subject was asked to 'hollow' their lower abdomen (resulting in a co-contraction of TrA and dMF) the stiffness of the SIJ increased. These authors state that "under gravitational load, it is the transversely oriented muscles that must act to compress the sacrum between the ilia and maintain stability of the SIJ". Although multifidus is not oriented transversely, both it and several other muscles (erector spinae, gluteus maximus, latissimus dorsi, and internal oblique) can generate tension in the thoracodorsal fascia and thus impart compression to the posterior pelvis (Barker et al 2004, van Wingerden et al 2004).

The muscles of the pelvic floor play a critical role in the maintenance of urinary and fecal continence (Ashton-Miller et al 2001, Barbic et al 2003, Bø & Stein 1994, Deindl et al 1993, 1994, Sapsford et al 2001) and recently attention has been directed to their role in the stabilization of the joints of the pelvic girdle (Lee & Lee 2004b,c,d, O'Sullivan et al 2002, Pool-Goodzwaard 2003). The research suggests that motor control (sequencing and timing of muscular activation) plays a critical role in the ability to effectively force close the urethra, stabilize the bladder and control motion of the SIJ during loading tasks.

The active straight leg raise test (ASLR) examines the ability of the patient to transfer load through the pelvis in supine lying and has been validated for reliability, sensitivity and specificity for pelvic girdle pain after pregnancy (Mens et al 1999, 2001, 2002). It can also be used to identify non-optimal stabilization strategies for load transfer through the pelvis. The supine patient is asked to lift the extended leg 20 centimeters and to note any effort difference between the left and right leg (does one leg seem heavier or harder to lift). The strategy used to stabilize the lumbopelvic region during this task is observed and the effort scored from 0 to 5. The pelvis is then compressed passively (anterior to simulate the force of TrA and posterior to simulate the force of the dMF (Lee & Lee 2004a, c)) and the ASLR is repeated; any change in strategy and/or effort is noted.

Subsequently, the patient's ability to voluntarily contract the TrA, dMF and the pelvic floor is assessed and the results correlated to the findings of the ASLR test. To assess the ability of the left and right TrA to cocontract in response to a pelvic floor cue, the abdomen is palpated just medial to the ASISs and the patient is instructed to gently squeeze the muscles around the urethra or to lift the vagina/testicles. When a bilateral contraction of TrA is achieved in isolation from the internal oblique, a deep tensioning will be felt symmetrically and the lower abdomen hollows (moves inward) (O'Sullivan et al 2003, Richardson et al 1999).

The dMF is palpated bilaterally close to the spinous process or the median sacral crest. In a healthy system, a cue to contract the pelvic floor should result in a co-contraction of the dMF (clinical experience – Lee & Lee 2004a,c). When a bilateral contraction of dMF is achieved the muscle can be felt to swell symmetrically beneath the fingers (Richardson et al 1999). There should be no evidence of substitution from the more superficial multisegmental fibers of the multifidus which will produce extension of the lumbar spine and a phasic bulge of the substituting muscle. TrA should co-activate with the dMF and both muscles can be palpated unilaterally to assess co-contraction during a verbal cue to contract the pelvic floor (clinical experience – Lee & Lee 2004a,c).

The activation patterns of the deep muscle system can also be assessed using rehabilitative ultrasound imaging (Henry & Westervelt 2005, Lee & Lee 2004c, Richardson et al 1999).

In the Supplements part there are the describe and illustrate the basic subjective and objective examination for the lumbar spine, pelvic girdle, and hip.

A common model of lumbar stability shows the musculature surrounding the spinal vertebrae forming a cylinder. The top of the cylinder is the diaphragm, the bottom is the pelvic floor, and the wall is formed by segmentally attaching abdominal and posterior spinal musculature, specifically the transversus abdominus and the segmental fibers of lumbar multifidus (Richardson C et al 1999). There is growing evidence that demonstrates how these muscles coordinate their activity to stabilize the spine. For example, transversus abdominis has been shown to co-contract with: the diaphragm (Hodges PW et al 1997); the pelvic floor (Sapsford RR et al 2001); and the deep fibres of lumbar multifidus (Moseley GL et al 2002). According to this model, the psoas major is ideally located to assist in a stabilizing role. Psoas major has intimate anatomical attachments to the diaphragm and the pelvic floor. This unique anatomical location allows the psoas major to act as a link between these structures and may help in maintaining the stability of the lumbar cylinder mechanism. This can be thought of conceptually as a supporting rod in the middle of the cylinder. Early biomechanical literature suggested that the psoas major might aid in the stabilization of the lumbar spine through its large potential to generate compressive forces, which would result in increased spinal stiffness.30

McGill (2002) conceptualizes lumbar spine stability as a fishing rod placed upright and vertical with tensioned guy wires attached at different levels along its length andthose guy wires being attached to the ground in a circular pattern. Here the rod represents the lumbar vertebrae and the guy wires are the various muscles attaching to the lumbar spine. Reducing the tension on one of the muscles (wires) will allow the spinal segment (rod) to buckle and allow spinal injury to occur (Juker et al 1998) showed that the psoas major counteracts the action of iliacus during hip flexion.

They believe that the iliacus would torque the pelvis into anterior pelvic tilt and that the psoas major works against these forces, adding to the stiffness within the pelvis and the lumbar spine. An activated and stiffened psoas major will contribute some shear stiffness to the lumbar motion segment (Quint U et al 1998, Wilke HJ et al 1995).

Chapter VI

6. Conclusion

The SI joints are an important source of pain and activity intolerances. Force closure of the SI joints requires appropriate muscular, ligamentous and fascial interaction. The ASLR test can help to determine if a specific treatment is effective. Advice about posture and support, manipulation of the SI joints along with manual therapy of related muscles and fascia, and exercise of key stabilizers are all important components in reestablishing lumbopelvic stability. Treatment for the impaired pelvic girdle must be prescriptive since every individual has a unique clinical presentation.

Exercises for motor control are aimed at retraining strategies of muscular patterning so that load transfer is optimized through all joints of the kinetic chain. Optimal load transfer occurs when there is precise modulation of force, coordination, and timing of specific muscle contractions, ensuring control of each joint (segmental control), the orientation of the spine (spinal curvatures, thorax on pelvic girdle, pelvis in relation to the lower extremity), and the control of postural equilibrium with respect to the environment. The result is stability with mobility, where there is stability without rigidity of posture, without episodes of collapse, and with fluidity of movement. Optimal coordination of the myofascial system will produce optimal stabilization strategies.

- The ability to find and maintain control of neutral spinal alignment both in the lumbopelvic region and in relationship to the thorax and hip.

- The ability to consciously recruit and maintain a tonic, isolated contraction of the deep stabilizers of the lumbopelvis to ensure segmental control and then to maintain this contraction during loading.

- The ability to move in and out of neutral spine (flex, extend, laterally bend, rotate) without segmental or regional collapse.

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Supplements

Subjective exmanination

Mode of onset

How did the problem begin - suddenly or insidiously? With respect to wound repair is the patient presenting during the substrate, fibroblastic, or maturation phase of healing?

- Was there an element of trauma? If so, was there a major traumatic event over a short period of time, such as a fall, or was there a series of minor traumatic events over a prolonged period of time, such as the habitual use of improper lifting technique?

- Is this the first episode requiring treatment or has there been a similar past history of events? If this is a repeat episode, how long did it take to recover from the previous one and was therapy necessary at that time? If so, what therapy was beneficial, if any?

- Is the problem a consequence of a pregnancy and/ or delivery? If so, when did the symptoms begin, what were the nature of the delivery, and how much trauma occur red to the pelvic floor?

Pain/Dysesthesia

- Exactly where is the pain/dysesthesia? Is it localized or diffuse and can its quality be described?

- How far down the limb or limbs do the symptoms radiate?

- Which activities (including how much) will aggravate the symptoms?

- What effect does prolonged sitting, standing, walking, stair-climbing and descent, rolling over in bed, getting in/ out of a chair/car, cough, and/ or sneeze have on the pain/ dysesthesia? Does the aggravating activity induce more vertical or horizontal loading (or both)?

- What activities (including how much) provide relief?

Sleep

- Are the symptoms interfering with sleep? Does rest provide relief?
- What kind of bed is being slept in and what position is most frequently adopted?

Occupation/ leisure activities

- What level of physical activity does the patient consider normal and essential for return to full function?
- What are the patient's goals from therapy? The specifics of both the patient's occupa tion and sport are required if rehabilitation is to be successful and complete.

General information

- What is the status of the patient's general health?
- Is the patient currently taking any medication for this or any other condition?
- What are the results of any adjunctive diagnostic tests (i.e., X-ray, computed tomography (CT) scan, magnetic resonance imaging, laboratory tests, etc.)?
- Is there any urinary incontinence? If so, is it stressed, urge, or mixed?

Objective exmanination

Bogduk (1997) states that biomechanical diagnoses require biomechanical criteria. He notes that "Pain on movement is not that criterion." Tests which aim to analyze the mobility and stability of a joint are required to achieve these criteria. Several biomechanical tests of the SIJ have been criticized with regard to their reliability, validity, and specificity (Potter & Rothstein 1985, Carmichael 1987, Dreyfuss et al 1994, 1996, Laslett & Williams 1994, Paydar et al 1994, Maigne et al 1996, Bogduk 1997, Buyruk et al 1997, Laslett 1997). From this research, it has been suggested that manual testing of the SIJ is unreliable and therefore should be abandoned. This conclusion has not been reached with other joints of the body.

Stability tests for the knee joint (Lachman's and the anterior drawer tests) are commonly accepted amongst both physio therapists and orthopedic surgeons (Reid 1992) even though their reliability, validity, and specificity have been questioned (Cooperman et al 1990). The results from the latter intertester reliability study clearly showed poor agreement in all areas. In spite of this research, the Lachman's test remains widely used for evaluation of stability at the knee joint.

Wurff et al (2000) conducted a systematic literature review of the reliability studies for both pain provocation and mobility tests for the SIJ. They conclude that individually there is no reliability for any test. Intertester reliability has long been an issue and there is some suggestion (Strender et al 1997, Herrington 2000, Damen et al 2002a) that tester experience and standardization of testing are strong variables which influence the reliability of any test.

The tests for spinal and SIJ function (i.e., mobility / stability, not pain) continue to evolve and as we understand more about the factors which influence the test findings, hopefully they will be able to withstand the scrutiny of scientific research and take their place in a clinical evaluation which follows an integrated model of function.

Gait

Careful observation of the patient's gait can be informative since walking requires optimal lurnbopelvic- hip function. Initially, deviation of the top of the head in the vertical and/or coronal planes is noted. When gait is optimal, there is minimal deviation of the head in either plane. Failed load transfer through the pelvis and/or hip joint manifests as a deviation in the coronal plane of either the entire body (Trendelenburg gait) or of the pelvis rela tive to the lumbar spine and hip (subtle hip drop /Trendelenburg sign). Alterations in stride length and timing can be indicative of mobility or stability dysfunction within the lurnbopelvic- hip complex.

Posture

Postural asymmetry is not necessarily indicative of pelvic girdle dysfunction; however, pelvic girdle dysfunction is often reflected via postural asymmetry. The impact of a specific impairment (intrinsic or extrinsic to the pelvic girdle) is often reflected in the patient's posture.

Optimal posture requires the following. In the sagittal plane, a vertical line should pass through the external auditory meatus, the bodies of the cervical vertebrae, the glenohumeral joint, slightly anterior to the bodies of the thoracic vertebrae transecting the vertebrae at the thoracolumbar junction, the bodies of the lumbar vertebrae, the sacral promontory, slightly posterior to the hip joint and slightly anterior to the talocrural joint and naviculo-calcaneo-cuboid joint. The primary spinal curve should be maintained, i.e., lumbar lordosis, thoracic kyphosis. The innominates should not be rotated excessively relative to one another and the sacrum should not be rotated between them. The anterior superior iliac spine (ASIS) of the innominate should lie in the same coronal plane as the pubic symphysis such that the innominate is vertical over the femoral shaft.

In the coronal plane, the clavicles should be symmetrical and slightly elevated, the manubrium and sternum vertical (with the manubriosternal junction in the same plane as the pubic symphysis and ASISs of the innominate), and the scapulae should rest in slight upward rotation (abduction) with the inferior angle on the chest wall.

Dynamic movements

These tests examine the integrated biomechanics of the low back, pelvis, and hip. Effective load transfer requires optimal function of the passive (form closure), active (force closure), and neural systems (motor control).

Forward bending (standing): Initially, the patient is instructed to forward bend and the ease with which the patient does so is noted. Repeat the test three to four times. The apex of the sagittal curve for the whole body and then specifically note:

1. The relative intersegmental mobility of the lumbar spine (segmental kyphosis/lordosis or rotation). The spinal segments should flex symmetrically without shifting or hinging.

2. The paravertebral fullness. It should be equal on the left and right sides of the spinal column.

3. The rela tive mobility of the pelvic girdle on the femoral heads (the hip joint can be palpated anteriorly for this). The pelvic girdle should anteriorly tilt symmetrically over the femoral heads.

4. Any intrapelvic rotation. Palpate both innominates at the inferior aspect of the posterior superior iliac spine (PSIS) and at the iliac crest. No intrapelvic rotation or torsion should occur.

5. The maintenance of sacral nutation throughout the full forward bend. Palpate the innominate with one hand and the median sacral crest at S2, or the inferior lateral angle (ILA) of the sacrum, with the other. As the trunk bends forward there is an increase in the activation of mu ltifidus. If the sacral base is palpated directly parallel to the PSIS (lateral to the median sacral crest), the bulging of the sacral multifidus pushes the thumb posteriorly and it is easy to interpret this as counternutation of the sacrum when in fact deep to the multifidus the sacrum is actually nutating. Therefore, the median sacral crest at S2, or the ILA, is a more reliable point to palpate the sacrum since there are no muscle fibers here to confuse the tester.
   The sacrum may be felt to nutate during the first few degrees of the forward bend (depending on the starting position of the sacrum) and should remain nutated throughout the forward bend.

Backward bending (standing): Initially, the patient is instructed to backward bend and the ease with which the patient does so is noted. Repeat the test three to four times. The apex of the sagittal curve for the whole body and then specifically note:

1. The relative intersegmental mobility of the lumbar spine (segmental kyphosis/lordosis or rotation). The spinal segments should extend symmetrically without shifting or hinging.
2. The relative mobility of the pelvic girdle on the femoral heads (the hip joint can be palpated anteriorly for this). The pelvic girdle should posteriorly tilt symmetrically on the femoral heads.
3. Any intrapelvic rotation. Palpate both innominates at the inferior aspect of the PSIS and at the iliac crest. No intrapelvic rotation or torsion should occur.

Lateral bending (standing): Initially, the patient i s instructed to laterally bend and the ease with which the patient does so is noted. Repeat the test three to four times.

1. The relative intersegmental mobility of the lumbar spine (segmental sideflexion/rotation). The spinal segments should sideflex symmetrically.
2. The relative mobility of the pelvic girdle on the femoral heads (the hip joint can be palpated). The pelvic girdle should laterally translate and laterally tilt relative to the femora.
3. Any intrapelvic rotation. Palpate both innominates at the inferior aspect of the PSIS and at the iliac crest. In a mobile individual some intrapelvic motion occurs during lateral bending in standing such that in left lateral bending the right innominate posteriorly rotates relative to the left and the sacrum rotates slightly to the right. Relatively, both sides of the sacrum remain nutated compared to the left and right innominate and therefore stability is ensured for load transfer.

   Repeat the test and note the consistency linconsistency of any positive findings and the ease with which the patient is able to lateral bend repeatedly.

Axial rotation (standing): Initially, the patient is instructed to rotate and the ease with which the patient does so is noted. Repeat the test several times and note:

1. The relative intersegmental mobility of the lumbar spine (segmental sideflexionl rotation). The spine should rotate without "kinking."

2. The relative mobility of the pelvic girdle on the femoral heads (the hip joint can be palpated anteriorly for this). The pelvic girdle should rotate such that there is relative internal rotation of the ipsilateral hip joint and external rotation of the contralateral hip joint.

3. Any intrapelvic rotation. Palpate both innominates at the inferior aspect of the PSIS and at the iliac crest. In a mobile individual some intrapelvic motion occurs such that in left axial rotation the right innominate anteriorly rotates relative to the left and the sacrum rotates slightly to the left. Relatively, both sides of the sacrum are nutated compared to the left and right innominates and therefore stability is ensured for load transfer.

One leg (standing): This test is also known as the Gillet test, stork test, or kinetic test and examines the ability of the low back, pelvis, and hip to transfer load unilaterally (support phase) as well as for the pelvis to allow intrapelvic rotation (Hungerford 2002). Initially, the patient is instructed to stand on one leg and to flex the contralateral hip and knee towards the waist. The ability to perform this task is observed. The pelvis should not anteriorly, posteriorly, laterally tilt nor rotate in the transverse plane as the weight is shifted to the supporting limb. The test is repeated on the opposite side. Subsequently, the intrapelvic motion which occurs during this task can be examined as follows:

1. Hip flexion phase (ipsilateral kinetic test). With one hand, palpate the innominate at the inferior aspect of the PSIS and at the iliac crest on the non-weight-bearing side. With the other hand, palpate either the median sacral crest at S2 or the ILA of the sacrum on the same side as the innominate being palpated. Instruct the patient to flex the ipsilateral hip (same side you are palpating) and note the posterior rotation of the innominate relative to the sacrum.

Compare the amplitude and quality (resistance) of this movement to the contralateral side. This is not a test for mobility of the SIJ but rather a test of osteokinematic motion of the low lumbar vertebrae, the innominate, and the sacrum. Many factors can impede osteokinematic motion, the SIJ is one.

2. Support phase:

   a. On the weight-bearing side, with one hand, palpate the innominate at the inferior aspect of the PSIS and at the iliac crest. With the other hand, palpate either the median sacral crest at S2, or the ILA of the sacrum, on the same side as the innominate being palpated. Instruct the patient to flex the contralateral hip (side are not palpating) and note the motion of the innominate relative to the sacrum (contrala teral kinetic test). Especially note the movement that occurs as the weight is transferred on to the supporting leg (initial loading) and the contralateral leg is coming off the ground. The innominate should either posteriorly rotate or remain still relative to the sacrum (in a posteriorly rotated position; what is observed will depend on the starting position of the innominate).

   b. On the weight-bearing side, palpate the innominate with one hand and the femur with the other. Instruct the patient to flex the contralateral hip (side are not palpating) and note the motion of the innominate relative to the femur. The innominate should either move towards the vertical position (extend) or remain vertical relative to the femur.

      A positive test occurs when the innominate anteriorly rotates or internally rotates relative to the sacrum (failed load transfer through the pelvic girdle) (Hungerford et al 2001, Hungerford 2002) or flexes relative to the femur (failed load transfer through the hip joint). This is a less stable position for load transfer through both the pelvis and the hip.

Form closure – lumbar spine

The following tests examine the mobility and passive stability of the joints of the lumbar spine. Form closure analysis requires an evaluation of two zones of motion: the neutral zone and the elastic zone (Panjabi 1992b). The neutral zone is a small range of movement near the joint's neutral position where minimal resistance is given by the osteoligamentous structures (joint play from 0 to R1 or first resistance). The elastic zone is the part of the motion from the end of the neutral zone up to the joint's physiological limit (end-feel from R1 to R2).

Panjabi (1992b) noted that joints have non-linear load-displacement curves. The non-linearity results in a high degree of laxity in the neutral zone and a stiffening effect toward the end of the range of motion. He found that the size of the neutral zone may increase with injury, articular degeneration, and/or weakness of the stabilizing musculature and that this is a more sensitive indicator than angular range of motion for detecting instability. He used a ball and bowl illustration to represent this change in the neutral zone. Lee & Vleeming (1998, 2004) suggest that the neutral zone is not only affected quantitatively (bigger or smaller), but also qualitatively (more or less resistance) when compression is increased or decreased across the joint.

Lumbar spine: Positional tests

To determine the position of L5 relative to the sacrum, the posteroanterior relationship between the transverse processes of the L5 vertebra and the sacral base is noted in neutral, full flexion, and full extension. The influence of muscular hypertonicity and/or atrophy should be considered when interpreting the positional findings.

Flexion With the patient sitting, feet supported, and the lumbar spine fully flexed, the lateral aspect of the L5 segment and the sacral base are palpated bilaterally. The posteroanterior relationship of the articular pillar of L5 relative to the sacral base is noted. A posterior right articular pillar of L5 relative to the sacral base is indicative of a right rotated position of L5-S1 in hyperflexion.

Extension With the patient prone and the lumbar spine fully extended, the L5 and then the sacral base are palpated laterally. The posteroanterior relationship of the articular pillar of L5 relative to the sacral base is noted. A posterior right articular pillar of L5 relative to the sacral base is indicative of a right rotated position of L5-S1 in hyperextension.

Lumbar spine: Passive tests of osteokinematic function (passive intervertebral motion: PIVM)

Flexion/extension With the patient sidelying, hips and knees flexed and supported on the therapist'sbe directly dorsal to the L3-L4 zygapophysealjoint. Palpate the pelvic girdle in an obliquely distolateral direction with the caudal arm. With the index and middle fingers of this hand, palpate L4. Passively sideflex and contralaterally rotate L3-L4 using an obli que force through both arms. Note the quantity and quality of segmental motion. Repeat the test for the other lumbar segments and then test sideflexion/rotation in the opposite direction by laying the patient on the opposite side.

Lumbar spine: Passive tests of arthrokinematic function (passive accessory vertebral motion: PAVM)

Superoanterior glide: left zygapophyseal joint L4-L5 A superoanterior glide of the left zygapophyseal Jomt occurs during flexion and right sideflexion L4-L5. With the patient in right sidelying, left hip and knee slightly flexed, right hip and knee extended, weave your cranial arm between the patient's left arm and thorax. This will give you good control of the thoracolumbar region during this test. With the cranial hand, palpate lateral to the interspinous space of L4-L5. With the caudal hand, palpate L5. Passively sideflex the segment to the right (i.e., produce a superoanterior glide of the left zygapophyseal joint). Analyze the two zones of motion (neutral zone from 0 to R1, and elastic zone from R1 to R2) for amplitude, resistance to motion, and end-feel.

Inferoposterior glide: right zygapophyseal joint L4-L5 An inferoposterior glide of the right zygapophyseal joint occurs during extension and right sideflexion L4-L5.

With the patient in left sidelying, right hip and knee slightly flexed, left hip and knee extended, weave cranial arm between the patient's right arm and thorax. This will give good control of the thoracolumbar region during this test. With the index finger of the cranial hand, palpate lateral to the interspinous space of L4-L5.

Passively sideflex the segment to the right (i.e., produce an inferoposterior glide of the right zygapophyseal joint). Analyze the two zones of motion (neutral zone, from 0 to R1, and elastic zone, from Rl to R2) for amplitude, resistance to motion, and end-feel.

Lumbar spine: Passive tests of arthrokinetic function

Compression With the patient lying supine and the hips and knees flexed, the lower extremities are cradled. Compression is applied to the lumbar segments by applying a cranial force parallel to the table through the flexed lower extremities.

Rotation: left rotation L4-L5 With the patient in right sidelying, left hip and knee slightly flexed, right hip and knee extended, palpate the left side of the spinous process of L4 with the cranial hand. With the long and ring fingers of the caudal hand, palpate the right side of the spinous process of L5. Left rotation, or left segmental torsion, is tested by fixing L4 and right-rotating L5 about a pure vertical axis beneath the L4 vertebra (the L4-L5 segment relatively left-rotates). Note the amplitude of the neutral zone, the resistance to motion within the neutral and the elastic zones, the quality of the end-feel of the elastic zone, and the provocation of pain or spasm.

Anterior translation: L4-L5 With the patient lying prone, palpate the spinous process of L4 with the pisiform of one hand. With the other hand, stabilize the sacrum and L5 with a caudal force (to prevent extension of the spine). Apply an anterior translation force to the L4 vertebra. Note the amplitude of the neutral zone, the resistance to motion within the neutral and the elastic zones, the quality of the endfeel of the elastic zone, and the provocation of pain or spasm. This test may also be done in the sidelying position by fixing the spinous process of the superior vertebra and taking the inferior vertebra posteriorly by applying compression along the flexed femurs.

Posterio rtranslation: L4-L5 With the patient sitting in a neutral lumbar spine position, arms crossed; palpate the interspinous space of L4-L5. To localize the force, flex the lumbar spine dovm to L3-L4, ensuring that L4-L5 remains in a neutral position. Fix L5 with the caudal hand and apply a pure posterior translation force through the trunk with the other arm / hand.

The amplitud e of the neutral zone, the resistance to motion within the neutral and the elastic zones, the quality of the endfeel of the elastic zone, and the p rovoca tion of pain or spasm are noted .

Lateral translation: L3- L4 With the patient sitting in a neutral lumbar spine position, arms crossed, palpate and stabilize L4 with an open web space grip. Fix L4 with this hand and apply a pure lateral translation force through the trunk with the o ther arm / hand. The amplitude of the neutra l zone, the resistance to motion within the neutral and the elastic zones, the quality of the end-feel of the elastic zone, and the provocation of pain or spasm are noted .

Pelvic girdle: positional girdle

Innominate When analyzing the position of the innominate bones, it is more reliable to use the entire ischial tuberosity bilaterally. Initially use the heels of both hands and then palpate the ischial tuberosity with the thumbs. Ensure that you are on the most inferior aspect of the tuberosity since a rotated innominate can change the apparent craniocaudal relationship between the left and right sides if palpating the dorsal aspect of the ischial tuberosity.

Sacrum The most reliable place for positional testing of the sacrum is the dorsal aspect of the ILA since at the sacral base the size and tone of multifidus can influence the findings. To determine the position of the sacrum, a comparison is made of the posteroanterior relationship of the ILA bilaterally. To find the ILA, begin by palpating the median sacral crest. Follow the crest inferiorly until you reach the sacral hiatus (unfused spinous processes of S4 and S5). From this point, palpate laterally until feel the lateral edge of the sacrum: this is the ILA. A posterior left ILA is indicative of a left rotated sacrum.

Pelvic girdle: passive tests of osteokinematic function (PIVM)

Anterior/posterior rotation: innominate With the patient in sidelying, hips and knees slightly flexed, palpate the ASIS of the innominate with the cranial hand. Let the fingers of this hand mold around as much of the innominate as possible. With the heel of the other hand, palpate the ischial tuberosity. Let the fingers of this hand mold around as much of the innominate as possible. Passively anteriorly and posteriorly rotate the innominate relative to the sacrum (remember the amplitude of SIJ movement is very small) and note the quantity and quality of the motion.

Nutation/counternutation: sacrum With the patientlying prone, palpate the apex of the sacrum with one hand and the midline of the sacral base with the other. Passively nutate and counternutate the sacrum relative to the innominates and note the quantity and quality of the motion.

Pelvic girdle: passive tests of arthrokinematic function (PAVM)

Inferoposterior glide: SIJ An inferoposterior glide of the innominate relative to the sacrum occurs at the SIJ durin g non-weight-bearing anterior rotation of the innominate. The patient is in crook lying with the knees comfortably supported over a bolster and arms by the sides. It is important to ensure that the patient is as relaxed as possible since even minimal activation of the local system (as well as activation of the longitudinal and oblique slings) can change the stiffness value of the SIJ. This has been confirmed via Doppler imaging under varying conditions of muscle contraction (Van Wingerden et al 2001, submitted, Richardson et al 2002).

The goal is to have the lumbopelvic region in a neutral position. Check to ensure that the pubic symphysis is level with the ASISs (no posterior pelvic tilt) and gently move theri bcage laterally from side to side to ensure the oblique abdominals and erector spinae muscles are not overactive.

Once we are sure that the patient is relaxed, palpate the medial aspect of the posterior iliac crest just above and medial to the PSIS) by sliding cranial hand beneath the pelvis. Do not press too deeply into the multifidus muscle to avoid nutating the sacrum.

With the heel of the other hand, palpate the ipsilateral ASIS and with the rest of this hand, the iliac crest. The first step is to determine the plane of the joint since there is a high degree of individual variance. Apply a gentle oscillatory force in an anteroposterior direction varying the inclination from slightly medial to slightly lateral. One of those planes will meet with the least amount of resistance: this is the joint plane. Once the plane of the joint is found, apply a small anterior rotation force to the innominate to produce an inferoposterior glide of the innominate relative to the sacrum at the SIJ. Analyze the two zones of motion (neutral zone from 0 to R1, and elastic zone from R1 to R2) for amplitude, resistance to motion, and end-feel. Compare the findings to the opposite side: symmetry is the norm, while asymmetry of stiffness, or laxity, is indicative of dysfunction (Buyruk et a1 1997, Damen et al 2002b).

Superoanterior glide: SIJ A superoanterior glide of the innominate relative to the sacrum occurs at the SIJ during non-weight-bearing posterior rotation of the innominate (Hungerford 2002). The patient's position and therapist's palpation points are identical to that described for testing the inferoposterior glide at the SIJ.

The first step is to determine the plane of the joint since there is a high degree of individual variance. Apply a gentle oscillatory force in an anteroposterior direction, varying the inclination from slightly medial to slightly lateral. One of those planes will meet with the least amount of resistance; this is the joint plane. Once the plane of the joint is found, apply a smallposterior rotation force to the innominate to produce a superoanterior glide of the innominate relative to the sacrum at the SIJ. Analyze the two zones of motion (neutral zone - from 0 to R1, and elastic zone - from R1 to R2) for amplitude, resistance to motion and end-feel. Compare the findings to the opposite side; symmetry is the norm, asymmetry of stiffness, or laxity, is indicative of dysfunction (Buyruk et al 1997, Damen et al 2002b).

Pelvic girdle: passive tests of arthrokinetic function

These tests are also used to detect a change in the neutral zone of motion of the SIJ or the pubic symphysis. They specifically evaluate the ability of the SIJ and pubic symphysis to resist vertical and horizontal plane translation (Lee 1992, 1997b, Lee &

Walsh 1996). Individually, neither vertical nor horizontal translation occurs physiologically, therefore these are unphysiological translatoric tests of stability. Clinically, they appear to be more sensitive to changes in the neutral zone than angular motion (anterior / posterior rotation).

Horizontal translation: SIJ and pubic symphysis The patient's position and therapist's palpation points are identical to that described for testing the inferoposterior glide at the SIJ. The first step is to determine the plane of the SIJ since there is a high degree of individual variance. Apply a gentle oscillatory force in an anteroposterior direction, varying the inclination from slightly medial to slightly lateral. One of those planes will meet with the least amount of resistance: this is the SIJ plane. Once the plane of the joint is found, apply a small posterior translation force to the innominate. Analyze the two zones of motion (neutral zone from 0 to R1, and elastic zone from R1 to R2) for amplitude, resistance to motion, and end-feel. Compare the findings to the opposite side: symmetry is the norm, while asymmetry of stiffness, or laxity, is indicative of dysfunction (Buyruk et a1 1997, Damen et al 2002b).

Vertical translation: SIJ and pubic symphysis The patient's position and therapist's posterior palpation points are identical to that described for testing horizontal translation at the SIJ. The therapist's caudal hand palpates the distal end of the femur or knee. The first step is to determine the plane of the joint since there is a high degree of individual variance. Apply a gentle oscillatory force through the femur in a craniocaudal direction, varying the inclination from directly cranial to cranial and slightly lateral. One of those planes will meet with the least amount of resistance: this is the SIJ plane. Once the plane of the joint is found, apply a small cranial and then caudal translation force to the innominate through the femur. Analyze the two zones of motion (neutral zone from 0 to R1, and elastic zone from R1 to R2) for amplitude, resistance to motion, and end-feel. Compare the findings to the opposite side: symmetry is the norm, while asymmetry of stiffness, or laxity, is indicative of dysfunction (Buyruk et al 1997, Damen et al 2002b).

Stability is not about how much movement there is or is not but rather about the symmetry of stiffness. Buyruk et al (1995 b) as well as Damen et al (2001) found that unstable SIJs had lower stiffness values and that symptomatic individuals demonstrated asymmetry in the values between their left and right sides. While the Doppler studies suggest that the stiffness value for the SIJ should be symmetric, they do not determine if the amount of stiffness in the vertical plane should equal that in the horizontal plane.

Clinically, it appears that an individual can have more or less stiffness in one plane than the other and yet still be symmetric when the planes are compared. For example, the stiffness found on testing vertical translation is comparable left and right and the stiffness found on testing horizontal translation is comparable left and right; however, the stiffness found on vertical translation is more or less than that found on horizontal translation. It appears that an individual can have differing amounts of form closure for different directions of force. Therefore, when applying these tests, the therapist should compare the stiffness value left and right for a particular direction of translation and not compare the stiffness value for vertical translation with horizontal translation on the same side; they may not necessarily be the same, yet may be quite normal and functional for that individual.

The neutral zone is analyzed by comparing the sense of ease with which the innominate glides in a parallel manner relative to the sacrum until the point of first resistance. The elastic zone is analyzed from R1 to R2 and the quality of the resistance is assessed as well as the provocation of any pain or muscle spasm. The findings are then compared to the patient's opposite side, comparing the anteroposterior glide left and right and the craniocaudal glide left and right. We cannot make any judgments regarding amplitude of motion (stiff, loose, normal) with this test since it has been shown that the range of motion at this joint is highly variable and making a statement regarding the amplitude implies knowledge of what is "normal." It is not possible to know what the patient's normal should be. We can only compare the left to the right side of the pelvis and look for symmetry.

Vertical translation: pubic symphysis The pubic symphysis can be specifically tested for vertical stability. With the heel of one hand, palpate the superior aspect of the superior ramus of one pubic bone. With the heel of the other hand, palpate the inferior aspect of the superior ramus of the opposite pubic bone. Fix one pubic bone and apply a slow, steady vertical translation force to the other. Analyze the two zones of motion (neutral zone from o to R1, and elastic zone from R1 to R2) for amplitude, resistance to motion, and end-feel as well as the reproduction of any symptoms.

Pelvic girdle: pain provocation tests

Pain provocation tests have shown good intertester reliability (Laslett & Williams 1994, Laslett 1997), although their validity and specificity have been questioned (Dreyfuss et al 1994, 1996, Wurff et al 2000). When combined with tests of function, certain provocation tests are useful when developing inclusion criteria for research (Vleeming et al 2002). They can also help to explain to patients why certain activities / exercises may be provocative to their condition. On occasion, it is necessary to treat the painful structure before function can be restored, particularly if the exercises being taught are aggravating a painful, inflamed structure.

Long dorsal ligament This structure is commonly tender to palpation in patients with pelvic pain (Vleeming et al 2002). The patient is lying prone with the head neutral and arms by the sides. With one hand, palpate the iliac crest at approximately the level of L3. Follow the iliac crest posteriorly until you drop off the PSIS.

At this point, should be dorsal to the long dorsal ligament, which can be felt as a vertically oriented band. Note any tenderness to palpation. Continue to palpate the ligament with one hand and apply a counternutation force to the sacrum. We should feel an increase in tension in the long dorsal ligament. If this is associated with increased pain, then this structure is a likely pain generator.

Sacrotuberous ligament Although the sacrotuberous ligament can be injured during a fall on the buttock, this structure is less often a source of pelvic pain. The patient is lying prone with the head neutral and arms by the sides. Palpate the ischial tuberosity with one thumb. From this point, palpate medially and cranially until reach the inferior arcuate band (medial band) of the sacrotuberous ligament. It should feel like ataut guitar string when we pronate and supinate the forearm. Continue to palpate the ligament and apply a nutation force to the sacrum, should feel an increase in tension in the sacro tuberous ligament. If this is associated with increased pain, then this structure is a likely pain generator.

Anterior distraction: posterior compression This test is not intended to stress a particular structure but rather tests for pain provocation when the pelvic girdle is compressed posteriorly and distracted anteriorly. If the SIJ is inflamed and an intraarticular synovitis is present, this test markedly increases the patient's pain. With the patient lying supine, the medial aspect of the ASIS is palpated bilaterally with the heels of the crossed hands. A slow, steady, posterolateral force is applied through the ASISs, thus distracting the anterior aspect of the SIJ and pubic symphysis and compressing the posterior structures. The force is maintained for 5s and the provocation and location of pain are noted.

Posterior distraction: anterior compression This test is not intended to stress a particular structure but rather tests for pain provocation when the pelvic girdle is compressed anteriorly and distracted posteriorly. If an intraarticular synovitis of the SIJ is present, this test also increases the patient's pain. With the patient sidelying, hips and knees comfortably flexed, the anterolateral aspect of the uppermost iliac crest is palpated. A slow, steady, medial force is applied through the pelvic girdle, thus distracting the posterior structures of the SIJ and compressing the anterior. The force is maintained for 5 s and the provocation and location of pain are noted.

Form closure – hip joint

The following tests examine the mobility and passive stability of the hip joint. As with the lumbar spine and pelvic girdle, form closure analysis requires an evaluation of two zones of motion: the neutral zone and the elastic zone; however, before any interpre tation of mobility can be made, the position of the femoral hea d with respect to the acetabulum must be determined. The hip joint is wider the influence of several large muscles and imbalance can cause a displacement of the femoral head and thus give the appearance of res tricted articular range of motion.

Hip: positional tests

With the patient standing, palpate the contour of the posterolateral buttock behind the greater trochanter and the anterior hip joint at the level of the inguinal ligament. If there is a large" divot" in the posterolateral buttock and the anterior hip structures feel like they are under considerable tension, it is likely that this individual is gripping with the deep external rotators of the hip. Overactivation of these muscles forces the femoral head anteriorly and has marked consequences for mobilety at the hip, low back, and pelvis.

With the patient supine, note the resting position of the legs. Overactivation of the external rotators of the hip will cause the legs to lie in external rotation at rest. Palpate the anterior femoral head in this position. If the femoral head is displaced anteriorly, its prominence will be very superficial and the structures between the hand and the femoral head can be quite tender. It is not uncommon for individuals to have a bilateral pattern of overactivation of the external rotators, therefore comparing to the opposite side is not always an option.

Since there is a wide individual variation of coxa vara, coxa valga, and angle of inclination of the femoral neck, specific measurements of where the greater trochanter is in relation to the ASIS is not always a reliable indicator of displacement of the femoral head. Clinically, consideration must be given to both the mobility findings and the positional findings to understand the significance of this positional test.

Hip: passive tests of osteokinematic function (PIVM)

Flexion With the patient lying supine, the flexed knee of the lower extremity to be tested is palpated with the caudal hand. The femoral head is palpated anteriorly with the other hand. The femur is passively flexed at the hip joint until posterior rotation of the ipsilateral innominate begins. At that point, the limit of available range for femoral flexion has occurred. Both the quantity of motion and the end-feel are noted. The test is repeated on, and compared to, the other side.

Extension With the patient supine lying at the end of the table, one femur is flexed, held by the patient, and supported against the therapist's lateral thorax. Ensure that no intrapelvic torsion has occurred. The anterior aspect of the iliac crest and the ASIS of the limb being tested are palpated with the cranial hand. With the caudal hand, the therapist guides the femur into extension until anterior rotation of the ipsilateral innominate begins. At that point, the limit of available range for femoral extension has occurred. Both the quantity of motion and the end-feel are noted. The test is repeated on, and compared to, the opposite side.

Abduction/adduction With the patient supine, lying at the end of the table, one femur is flexed, held by the patient, and supported against the therapist's lateral thorax. The anterior aspect of the iliac crest and the ASIS of the limb being tested are palpated with the cranial hand. With the caudal hand, the therapist guides the femur into abduction / adduction until lateral bending of the pelvic girdle beneath the vertebral column begins. At that point, the limit of femoral abduction /adduction has been reached. Both the quantity of motion and the end-feel are noted. The test is repeated on, and compared to, the opposite side.

Lateral/medial rotation With the patient lying supine, the lower extremity to be tested is palpated above the ankle with the caudal hand. The test can be performed in varying degrees of hip flexion/extension to assist in the differentiation between an articular and myofascial restriction. The anterior aspect of the iliac crest and the ASIS are palpated with the cranialhand. The femur is passively laterally /medially rotated until rotation of the innominate begins. At that point, the limit of available range for femoral rotation has occurred. Both the quantity of motion and the end-feel are noted. The test is repeated on, and compared to, the opposite side.

Combined movement test (in flexion) With the patient lying supine, the flexed knee of the lower extremity to be tested is palpated with the caudal hand. The anterior aspect of the iliac crest and the ASIS are palpated with the cranial hand. The femur is passively flexed, adducted, and medially rotated. If the femoral head is displaced anteriorly secondary to overactive external rotators, impingement will occur, and the patient will likely complain of anterior groin pain. Combined movement test (in extension) with the patient lying prone, the extended knee of the lower extremity to be tested is palpated with the caudal hand. The posterior aspect of the greater trochanter is palpated with the cranial hand. The femur is passively extended, medially rotated, and then adduc ted or abducted. If the femoral head is displaced anteriorly and the joint is stiff, arestriction of extension will occur. If the femoral head is displaced anteriorly and the anterior aspect of the capsule / labrum is lax, excessive extension will occur.

Hip: passive tests of arthrokinematic and arthrokineticfunction (PAVM)

Linear translation is relatively limited at the hip join t due to its high degree of form closure. Consequently, movement analysis of linear translation (arthrokinematics: PAVMs) will be less informative than analysis of the osteokinematic motion (PIVMs). With respect to stability, it is the elastic zone analysis which reveals the most information (quality of the end-feel).

Lateral distraction/compression With the patient lying supine and the femur flexed to 30° (res ting position of the rup joint), the proximal trugh is palpated. The joint is translated laterally by applying an inferolateral force parallel to the neck of the femur. The superior and inferior aspects of the head of the femur translate laterally in relation to the acetabulum while the fovea is distracted. Compression is applied by approximating the femur superomedially into the medial aspect of the acetabular fossa. Analyze the two zones of motion (neutral zone from 0 to R1, and elastic zone from R1 to R2) for amplitude, resistance to motion, and end-feel.

Superoinferior glide With the patient lying supine and the femur flexed to 30°, the proximal thigh is palpated. The superior aspect of the joint is distracted (the inferior aspect is compressed) by applying an inferior force along the longitudinal axis of the femur. The superior aspect of the joint is compressed (the inferior aspect is distracted) by approximating the femur superiorly into the superior aspect of the ace tabular fossa.

Analyze the two zones of motion (neutral zone from 0 to R1, and elastic zone from R1 to R2) for amplitude, resistance to motion, and end-feel.

Anteroposterior glide With the patient lying supine and the femur flexed to 30°, the proximal thigh is palpated. An anteroposterior glide is induced by applying a posterolateral force in the plane perpendicular to the line of the femoral neck. Analyze the two zones of motion (neutral zone from 0 to R1, and elastic zone from R1 to R2) for amplitude, resistance to motion, and end-feel.

Hip: pain provocation and global stability

Torque test This is a global test of passive stability and a pain provocation test for the ligaments of the hip joint. The intent is to stress all of the capsular ligaments simultaneously. If the test is painless, then the subsequent tests which help to differentiate the individual ligaments are not required. With the patient supine, lying close to the edge of the table, the ipsilateral femur is extended until anterior rotation of the innominate begins. The femur is then medially rotated to the limit of the physiological range of motion. The proximal thigh is palpated and a slow, steady, posterolateral force is applied along the line of the neck of the femur to s tress the capsular ligaments further. The amplitude of the neutral zone (should be zero), the resistance to motion within the elastic zone (should be very firm), the quality of the end-feel of the elastic zone and the provocation of pain or spasm are noted.

Inferior band of the iliofemoral ligament This ligament is taut when the femur is fully extended. If passive femoral extension elicits the greatest amount of pain, this ligament may be a nociceptive source.

Iliotrochanteric band of the iliofemoral ligament With the patient supine, lying close to the edge of the table, the ipsilateral femur is slightly extended, adducted, and fully laterally rotated. The distal femur is fixed against the therapist's thigh and the proximal femur is palpated. A slow, steady distraction force is applied along the line of the neck of the femur and the provocation of local pain is noted.

Pubofemoral ligament With the patient lying supine, the ipsilateral femur is slightly extended, abducted, and fully laterally rotated. The distal femur is fixed against the therapist's thigh and the proximal femur is palpated. A slow, steady distraction force is applied along the line of the neck of the femur and the provocation of local pain is noted.

Ischiofemoral ligament This ligament primarily limits internal rotation as well as adduction of the flexed hip (Hewitt et al 2002). With the patient lying supine, the ipsilateral femur is flexed, adducted, and fully medially rotated. A slow, steady distraction force is applied along the line of the neck of the femur and the provocation of local pain is noted.

Force closure and motor control

The following tests examine the integrity of the myofascial systems which provide dynamic stability for the lumbopelvic-hip region. Force closure and motor control analysis evaluate the patient's ability specifically to recruit both the local and global systems appropriately. In addition, tests are required to assess the impact of the force closure mechanism on form closure in both the lumbar spine and pelvic girdle.

The impact of an effective contraction of the local system on force closure of the lumbar spine and pelvic girdle depends on an intact anterior and posterior fascial connection. Anteriorly, this requires integrity of the abdominal fascia and posteriorly, multifidus must be of sufficient bulk to generate tension in the thoracodorsal fascia when it contracts.

Anterior abdominal fascia - test for diastasis of the linea alba

Pregnancy is a common, but not the only, cause for diastasis of the linea alba. The fascial anatomy renders the abdomen vulnerable just below the umbilicus, although separation of the fascia can occur along the entire length of the midline from the pubis to the xyphoid. With the patient in crook lying, palpate the linea alba in the mid line. Ask the patient to do a slow curl-up (activate the abdominals) and palpate for separation of the midline fascia. The separation is measured in finger widths. According to Sapsford et al

(1998), it is normal to feel 1-2 cm separation in the linea alba above the umbilicus and less below.

Deep fibers of multifidus

The deep fibers of multifidus are palpated with the patient in prone lying, head in neutral. In the lumbar spine, the "gutter" between the spinous process and the transverse process is palpated. In the pelvis, the deep fibers of the multifidus are palpated just lateral to the median sacral crest. The superficial and lateral fibers of multifidus belong to the global system (Moseley et al 2002) and in the pelvis attach to the posterior iliac crest lateral to the deep fibers. Press firmly but gently into the tissue and note the quality of the tissue (firmness) and the size of the muscle.

Compare the firmness / size to the contralateral side and to levels above and below. In dysfunction, it is common to find atrophy of the deep (medial) fibers and hypertonicity of the superficial or lateral fibers of multifidus.

Active straight leg raise test

The supine active straight leg raise (ASLR) test (Mens et al 1997, 1999, 2001, 2002) has been validated as a clinical test for measuring effective load transfer between the trunk and lower limbs. When the lumbopelvic-hip region is functioning optimally, the leg should rise effortlessly from the table (effort can be graded from 0 to 5) (Mens et a1 1999) and the pelvis should not move (flex, extend, laterally bend, or rotate) relative to the thorax and / or lower extremity. This requires proper activation of the muscles (both in the local and global systems) which stabilize the thorax, low back, and pelvis. Several compensation strategies have been noted (Lee 1999, 2001a, Richardson et al 1999) when stabilization of the lumbopelvic region is lacking. The ASLR test can be used to identify these strategies. The application of compression to the pelvis has been shown (Mens et al 1999) to reduce the effort necessary to lift the leg for patients with pelvic pain and instability. It is proposed (Lee 2002) that by varying the location of this compression during the ASLR.

The supine patient is asked to lift the extended leg off the table and to note any effort difference between the left and right leg (does one leg seem heavier or harder to lift). The strategy used to stabilize the thorax, the low back, and the pelvis during this task is observed. The leg should flex at the hip joint and the pelvis should not rotate or laterally, anteriorly or posteriorly tilt relative to the lumbar spine. The ribcage should not draw in excessively (overactivation of the external oblique muscles), nor should the lower ribs flare out excessively (overactivation of the internal oblique muscles). Overactivation of the external and internal oblique will result in a braced, rigid ribcage that limits lateral costal expansion on inspiration. The thoracic spine should not extend (overactivation of the erector spinae), nor should the abdomen bulge (breath-holding: Valsalva). ln addition, the thorax should not shift laterally relative to the pelvic girdle. The provocation of any pelvic pain is also noted at this time.

Simulation of the local system The pelvis is then compressed passively and the ASLR is repeated; any change in effort and / or pain is noted. The location of the compression can be varied to simulate the force which would be produced by optimal function of the local system. Although still a hypothesis, clinically it appears that compression of the anterior pelvis at the level of the ASISs simulates the force produced by contraction of lower fibers of transverses abdominis and compression of the posterior pelvis at the level of the PSISs simulates that of the sacral multifidus. Compression of the anterior pelvis at the level of the pubic symphysis simulates the action of the anterior pelvic floor whereas compression of the posterior pelvis at the level of the ischial tuberosities simulates the action of the posterior pelvic wall and floor. Compression can also be applied to one side anteriorly and simultaneously to the opposite side posteriorly. We are looking for the location where more (or less) compression reduces the effort necessary to lift the leg.

Simulation of the global system The thorax and pelvis are compressed obliquely to simulate the action of the oblique slings of the global system. Compression of the right anterolateral thorax towards the left side of the pelvis simulates the action of the left rotators of the trunk which include (but are not limited to) the right external oblique and the left internal oblique. Alternately, lengthening of a particular sling may be required.

Decompression of the left anterolateral thorax away from the right side of the pelvis simulates a release of the right rotators of the trunk. Once again, we are looking for the location where more (or less) compression reduces the effort necessary to lift the leg.

Active bent leg raise test

Further analysis of both muscle recruitment and timing is necessary to confirm the findings of the ASLR and to plan an effective exercise program. With the patient in crook lying, palpate the transversus abdominis deep in the abdomen approximately 2.5 cm medial to the ASIS. When the transversus abdominis contracts, an increase in tension (not bulging) is felt at this point. When the internal oblique contracts, a distinct bulging is felt.

With the other hand, palpate multifidus at the level where atrophy was noted. Ask the patient to lift the foot off the table, keeping the hip and knee flexed. The impact of this lesser load on the motor control strategy used to stabilize the lumbopelvic region. Note the ability to maintain a stable low back and pelvic girdle and, in addition, note the recruitment pattern of the lower abdominals (deep tension of transverses abdominis versus a fast bulging of internal oblique) and deep (slow tonic swelling) versus superficial (fast phasic bulging) multifidus. Both the local and global systems are required to achieve this task; however, in dysfunction the global system commonly dominates over the local.

Local system: co-contraction analysis

In health, the local system should co-contract in response to a command which begins with intention. This system is anticipatory and should respond prior to the activation of the global system. Global muscles do things (move joints) whereas the local muscles prepare the region for the impending load and respond to the thought of doing something. Therefore imagining or thinking about (preparing), but not actually doing a movement, appears to be a more effective way of accessing the appropriate neural pathways to the local system.

With the patient in crook lying, palpate the transverses abdominis deep in the abdomen approximately 2.5 cm medial to the ASIS. With the other hand, palpate multifidus at the level where atrophy was noted. To test the integrity of the neural pathway to transversus abdominis, multifidus, and the pelvic floor the following verbal cues are given and the response of the local system is noted:

a. Slowly and gently draw thr lower abdomen in.

b. Slowly and gently squeeze the muscles around your urethra as if to stop the urine flow.

c. Slowly and gently draw the vagina (or testicles) up into the body.

d. Imagine there is a wire connecting the hip bones anteriorly [ASISs] from the left to right side. Think about generating a force which would draw these two bones together.

e. Imagine there is a wire connecting the hip bones posteriorly (PSISs) from the left to right side. Think about genera ting a force which would draw these two bones together.

If the patient is able to connect and to co-contract the muscles of the local system, you should feel a deep, light tension develop in the transversus abdominis and a slow, tonic swelling posteriorly in the deep fibers of multifidus. We should not feel a fast, phasic bulging of the internal oblique, nor a rapid superficial contraction from the superficial fibers of multifidus. The lumbopelvic region should remain still - no motion should be seen. Palpate both sides and look for equal contraction and timing for both sides of the transversus abdominis and multifidus in response to these verbal cues.

The functional pelvic floor (muscles and the fascia) can only be properly assessed with internal palpation techniques; however, the impact of the functional floor on bladder position and support can be assessed via ultrasound (US) imaging.

US is a useful way to visualize some of the abdominal musculature (internal oblique, transversus abdominis), multifidus, and pelvic floor during verbal cuing (using intention) as well as during functional load transfer activities (ASLR). If the patient is able to isolate the muscles of the local system appropriately, the endurance of the local system can be assessed. The patient should be able to maintain the co-contraction for 10 srepeated 10 times while breathing normally. The co-contraction should also be maintained when loads are added; this ability can be assessed by adding leg loading (i.e., heel slides, hip flexion) while palpa ting transverses abdominis and multifidus and ensuring that co-contraction is maintained.

Local system and the neutral zone

When the force closure mechanism is effective, co-contraction of the muscles of the local system should compress the joints of the lumbar spine (Hodges et al 2003b) and the SIJs (Richardson et al 2002), thereby increasing stiffness. To test the status of the active force closure mechanism, the patient is first instructed to recruit the local system (transverses abdominis, multifidus, and pelvic floor). This instruction may take a few sessions to master. Once the patient is able to sustain a tonic co-contraction of the local system, the effect of this contraction on the stiffness of the lumbar zygapophyseal/ SIJ is assessed by repeating the form closure tests for translation while maintaining a gentle co-contraction of the local system. The joint stiffness should increase and no relative motion between the innominate and sacrum should be felt (the neutral zone of motion should be reduced to zero). This means that an adequate amount of compression has occurred and the force closure mechanism is effective. If the local system is contracting appropriately and has no effect on the stiffness of the joint, then the active force closure mechanism is ineffective for controlling shear. This is a poor prognostic sign for successful rehabilitation with exercise.

Global system slings: strength analysis

The global system of muscles is essentially an integrated sling system, comprising several muscles, which produces forces. A muscle may participate in more than one sling and the slings may overlap and interconnect depending on the task being demanded. The hypothesis is that the slings have no beginning or end but rather connect to assist in the transference of forces. It is possible that the slings are all part of one interconnected myofascial system and the particular sling (anterior oblique, posterior oblique, lateral, longitudinal), which is identified during any motion is merely due to the activation of selective parts of the whole sling.

The identification and treatment of a specific muscle dysfunction (weakness, inappropriate recruitment, tightness) is important when restoring global stabilization and mobility (between the thorax and pelvis or between the pelvis and legs) and for understanding why parts of a sling may be inextensible (tight) or too flexible (lacking in support). It is important to test for muscle strength and length; the reader is referred to Kendall et al (1993) for a detailed review of how to test specific muscles not covered in this text. Because a muscle seems weak to specific testing does not mean that the muscle is weak. It merely implies that the sling is not able to resist the force you are applying and it could be due to weakness (or lack of recruitment) of any muscle along that sling or an insufficient recruitment of the local system.

Four slings specific to the lumbopelvic region are described below. They reflect the anatomical connections observed by Vleeming et al (1995a, b) and are commonly involved in patients with lumbopelvic dysfunction. However, these are not the only slings which require consideration. The global system of muscles is essentially an integrated sling system, comprising several muscles, which produces forces. A muscle may participate in more than one sling and the slings may overlap and interconnect depending on the task being demanded.

The posterior oblique sling This sling consists, in part, of the gluteus maximus and the contra lateral latissimus dorsi and the intervening thoracodorsal fascia. The lower part of this sling is tested by resisting extension of the leg. Watch, and feel, for the give in the sling; where the loss of control occurs. The upper part of this sling is tested by resisting terminal elevation of the arm. Watch, and feel, for the give in the sling; where the loss of control occurs.

When the gluteus maximus is weak, the buttock appears flattened and the gluteal fold may be lower on the weak side.

The gluteus maximus is specifically tested in the prone position. The patient is asked to squeeze the buttocks together and the ability to do so is palpated. If the patient is able to isolate an effective contraction, he or she is then asked to perform a concentric contraction by extending the femur with the knee flexed. Resistance is then applied to the extended femur. Careful observation of the effects of this contraction on the position of the lumbar spine and pelvic girdle gives the examiner further information on muscles in the res t of this sling.

It is not uncommon to find positional weakness of the gluteus maximus muscle in patients with a chronically anteriorly rotated innominate. This position lengthens the gluteus maxirnus muscle and, when this muscle is tested in its shortened position, a marked weakness will be found and the femur will "give" relative to the pelvic girdle. The latissimus dorsi is isolated by resisting adduction of the extended, medially rotated arm. This muscle tends to tighten or become hypertonic and its length test will be described below.

The anterior oblique sling This sling consists, in part, of the oblique abdominalsand the contra lateral adductors of the thigh. When the anterior system is weak, the rib cage appears "posteriorly rotated" in standing and extended in supine lying, especially when the trunk is loaded during the ASLR. The anterior slings can be tested bilaterally during a sequenced curl-up. The therapist monitors the infrasternal angle and observes the ability of the patient to flex the thorax sequentially. The patient is then asked to continue flexing the lumbar spine through to a full sit-up. When this s ling is weak (or excessively resisted by hypertonicity of the posterior slings), there is an absence of sequential spinal movement (parts of the spine remain extended) and the lower extremities tend to abduct and externally rotate. Unilateral weakness presents as a thoracolumbar rotation (often associated with the lateral shift of the thorax du ring the curl-up).

The lateral sling The gluteus medius/minimus and the tensor fascia latae are significant muscles of this sling and work together to stabilize the pelvic girdle at the hip joint. Traditionally, gluteus medius is thought to be an abductor of the hip; however, Gottschalk et al (1989) revisted the anatomy and potential action of this muscle and propose a different functional role.

They note that the gluteus medius muscle is comprised of three segments, each with its own innervation. The posterior fibers run parallel to the neck of the femur (horizontal) whereas the anterior and middle fibers are oriented more vertically. Their electromyogram (EMG) studies showed that the three parts of gluteus medius function physically; the onset of action was sequential from posterior to anterior; the posterior fibers fire first at heel strike while the anterior fibers show the greatest amplitude of activity during stance and single-leg support. They propose that the primary function of the posterior part of the gluteus medius (and the entire gluteus minimus) is to stabilize the femoral head (by compressing it into the acetabulum) during different positions of femoral/pelvic rotation during gait. They also propose that the anterior and middle parts (have a more vertical pull) help to initiate abduction; however, the main abductor of the hip is the tensor fascia latae.

To test the left lateral sling, the patient is right sidelying. The patient is requested to abduct the left leg, maintaining neutral alignment of the lumbar spine, pelvis, and hip. An adduction force is applied to the limb and the response observed. Watch, and feel, for the give in the sling; where the loss of control occurs.

To test the posterior fibers of gluteus medius the patient is sidelying with the leg to be tested uppermost. With the knee extended, the hip is positioned in slight extension, abduction, and external rotation. The patient is requested to hold the trunk and the leg still, as support is released. The response is then observed. The patient with weak posterior fibers of gluteus medius will tend to rotate the pelvis backwards to facilitate the use of the tensor fascia latae. Alternatively, the patient may sideflex the spine in an attempt to hold the leg. In both cases, stabilization of the lumbar spine has been lost in an attempt to achieve the task demanded. If the deep fibers of the sacral multifidus are not functional, this test may be positive and yet the posterior fibers of gluteus medius are relatively strong. Alternately, the posterior fibers of gluteus medius are tested as follows. The patient is sidelying with the hips and knees slightly flexed. The patient is instructed to maintain contact between the ankles and then to lift the top knee (externally rotate the hip). Resistance to external rotation is applied through the lateral aspect of the femur. When the posterior fibers of gluteus medius are weak, the leg gives way easily and the patient attempts to compensate by rotating the pelvis backwards to facilitate the use of the tensor fascia latae.

Alternatively, the patient may sideflex the spine in an attempt to hold the leg. If the deep fibers of the sacral multifidus are not functional, this test may be positive and yet gluteus medius is relatively strong.

Global system slings: length analysis

Muscle shortening can adversely affect the biomechanics of the lumbopelvic-hip region. The muscles which tend to tighten in the presence of dysfunction should be assessed for their extensibility. These muscles include latissimus dorsi, erector spinae, oblique abdominals, hamstrings, psoas major, rectus femoris, tensor fascia latae, short and long adductors, and piriformis / deep external rotators of the hip.

The posterior oblique sling and the latissimus dorsi The patient is sitting in a neutral lumbar spine position with the arms resting by the sides. Instruct the patient to rotate the trunk to the left and then to the right and note the quantity and quality of motion through the thoracic and lumbar spine. Subsequently, instruct the patient to flex the arms to 90°, and fully externally rotate and adduct the shoulders such that the hypothenar eminences are approximated. This position increases the tension through the latissimus dorsi muscle. From this position, instruct the patient to rotate the trunk to the left and then to the right. The quantity and quality of the motion are noted and compared to that observed with the arms by the side. The motion is markedly reduced in this position when the latissimus dorsi muscle is tight. The length of the full posterior oblique sling can be tested by added tension to the inferior components of the sling. In the sitting position, the patient is instructed to extend the left knee. The ability to do so without posteriorly tilting the pelvis is observed. From this position, the arms are flexed to 90°, fully externally rotated and adducted, and the trunk is rotated to the left. This is a full stretch for the right posterior oblique sling.

The anterior oblique sling and the oblique abdominals In the supine lying position, the relative position of the thorax to the pelvic girdle is noted. When the oblique abdominals are overactive, the lumbar lordosis is absent and the pelvis rests in a posteriorly til ted position. In addition, the infrasternal angle is narrow either bilaterally or unilaterally. Isolated overactivation of the internal oblique is less common and tends to widen the infrasternal angle.

The longitudinal sling and the erector spinae With the patient sitting, feet supported and the vertebral column in a neutral position, the patient is instructed to forward bend. The quantity of the available motion, the symmetry / asymmetry of the paravertebral muscles, and the presence/ absence of a multisegmental rotoscoliosis may be indicative of unilateral tightness of the erector spinae muscles.

The longitudinal sling and the hamstrings The extensibility of the longitudinal sling can be assessed in standing or sitting. Optimally, the patient should be able to touch the toes and, with the knees extended, anteriorly tilt the pelvic girdle to at least a 90° angle relative to the femurs. Insufficient extensibility of the hamstrings is a common cause of tightness in this sling. To assess the length of the hamstrings specifically, the patient is lying supine with the lower extremity to be tested flexed at the hip joint to 90°. While maintaining the femur in this position, the knee is extended until the first resistance from the hamstrings is encountered. Medial and lateral rotation of the lower extremity will bias the test towards the lateral or medial hamstring. Both the quantity and the end-feel of motion are noted. The test is repeated on and compared to the opposite extremity.

According to Kendall et al (1993), when hamstring length is measured with the lumbar spine in a neutral position and no motion of the pelvic girdle is allowed, the femur should flex at the hip joint to 70°. Clinically, one needs to consider the patient's functional demands. This quantity of motion would be insufficient for a dancer or for a person who works in repe titive trunk flexion or who drives a car with a low seat. If the patient presents with lumbopelvic-hip pain and the pain provocation tests have revealed that the pelvic ligaments are a potential source of this pain, then the hamstrings need to be extensible enough to allow full forward bending while maintaining sacral nutation between the innominates. If the biceps femoris is unable to lengthen sufficiently, it will produce a force through the sacrotuberous ligament which resists the sacral nutation. As the innominates continue to flex on the femoral heads a relative counternutation of the sacrum occurs. The SIJ is now vulnerable since it is in a less stable position.

Iliacus, rectus femoris, tensor fascia latae, adductors With the patient supine, lying at the end of the table, one femur is flexed and supported against the therapist's lateral thorax. The anterior aspect of the iliac crest and the ASIS of the limb being tested are palpated. With the other hand, the therapist guides the femur in to extension, avoiding full knee flexion to test the length of the iliacus muscle and then with the knee flexed to test the length of the rectus femoris muscle. Both the quantity of femoral extension and knee flexion as well as the end-feel of motion are noted . The test is repeated on, and compared to, the opposite extremity.

Aninextensible iliacus muscle will restrict extension of the femur regard less of the position of the knee whereas an inextensible rectus femoris muscle will only restrict extension of the femur if the knee is flexed. According to Kendall et al (1993), in this position the thigh should reach the table and the knee should flex to 80°. If the anterior band of the tensor fascia la tae muscle is tight, full femoral extension will only occur if the hip is allowed to abduct. In addition, knee flexion with femoral extension results in lateraltibial rotation when the muscle is tight. If the tibial rotation is passively blocked during the test, knee flexion will be restricted.

The length of the adductors is tested with femoral abduction. The short adductors are tested with the knee flexed, the long ad doctors with the knee extended. Both the quantity and the end-feel of motion are noted. The test is repeated on, and compared to, the opposite extremity.

Piriformis/deep external rotators of the hip The patient is supine, the lower extremity comfortably flexed at the hip and knee. The lateral aspect of the iliac crest and the ASIS are palpated with the cranial hand, while the caudal hand flexes the femur to 90° of flexion. From this point, the femur is guided into adduction and internal rotation with the caudal hand while the cranial hand monitors the subsequent medial rotation of the innominate. The extensibility of the piriformis muscle has been reached when the innominate is felt to rotate medially. Both the quantity and the end-feel of this combined motion (flexion, adduction, and internal rotation) are noted. The test is repeated on, and compared to, the opposite extremity. Piriformis, together with the deep external rotators of the hip (obturator internus, externus, and quadrates femoris), can produce an anterior displacement of the femoral head such that adduction from the position of 90° of femoral flexion causes marked impingement pain in the groin. In addition, internal rotation from this position can be reduced to 0°. The external rotators are then specifically palpated for tender trigger points.

When the ischiococcygeus is hypertonic and supersensitive, the range of motion of the femur is not affected; however, a trigger point can be palpated just inferior to the superior attachment of the inferior arcuate band of the sacrotuberous ligament. Hypertonicity of the obturator intemus (together with piriformis) has a marked impact on the femoral head position and consequently the range of femoral motion. A tender trigger point is often found medial to the inferior attachment of the inferior arcuate band of the sacro tuberous ligament.

Pain provocation tests: contractile lesions

The presence and the location of pain evoked during resistance testing are correlated with the muscle's strength, thus enabling the therapist to reach a diagnosis of muscle "sprain" and / or rupture. Grades 1 and 2 muscle sprains are painfully strong when resisted isometrically, as opposed to grade 3 sprains (i.e., complete ruptures), which are relatively painfree and weak when resisted isometrically. Of course, there exists an entire spectrum of dysfunction between the two extremes. It must be remembered that con trac tions of muscles induce compression forces across joints and also increase tension in the various ligaments to which they attach. Therefore, a pain response may not be indicative of a muscle strain at all, but rather the pain may be coming from a joint which reacts to compression or from a ligament which is painful to stretch.

List of figuers

List of abbreviations

LBP	Low back pain
ECG	Electrocardiography
SIJ	Sacro iliac joint
DMF	Deep multifidius
ASLR	Active straight leg raise test
RSA	Stereophotogrammetric analysis
IAP	Intra-abdominal pressure
CAT	Computer-assisted tomography
MRI	Magnetic resonance imaging
L	Lumbar spine
S	Sacrum
PSIS	Posterior superior iliac spine
ASIS	Anterior superior iliac spine
ILA	Inferior lateral angle